Baseline data on the harbour porpoise, *Phocoena phocoena*, in relation to the intended wind farm site NSW, in the Netherlands

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ABSTRACT

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To evaluate the possible impact of the planned Near Shore Wind farm on harbour porpoises, a baseline study has been carried out to provide a thorough description of the ecological reference situation. Three methods were used to collect baseline data on harbour porpoise in the intended wind farm area as well as reference areas. Firstly, during a whole year echolocation sounds of the animals were collected via fixed hydrophones, so-called T-PODs. This will provide information on relative density of porpoises. Secondly, bi-monthly ship-surveys were conducted to obtain an estimate for density. Finally, hydrophones were towed behind the survey ship to corroborate the visual data. These studies proved that porpoises frequently occurred in the target area and also in the control sites. Intensity of the porpoise activity was clearly higher in winter months. Observations surpass the expectations with respect to the amount of animals and recording.

Keywords: clicks, Dutch Coast, Harbour porpoise, NSW, *Phocoena phocoena,* survey, T-POD, wind farms

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Photo's cover from top left clockwise:
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Contents

Preface 7

Summary 9

1 Introduction 11
- 1.1 Goal of this study 11
- 1.2 Status of the harbour porpoise in the Netherlands 11
- 1.3 Choice of methods 13

2 Methods 15
- 2.1 Site description 15
  - 2.1.1 Field schedule 17
- 2.2 T-PODS 17
  - 2.2.1 Technical description of T-PODS 18
  - 2.2.2 Field calibration of T-PODs 20
  - 2.2.3 Mooring technique 21
  - 2.2.4 Analysis of T-POD data 22
- 2.3 Ship-based surveys 27
  - 2.3.1 Statistical tests of survey data 27
- 2.4 Computerised Passive Acoustic Detection (Towed Hydrophones) 32
  - 2.4.1 Hydrophone and Analogue Electronics Module 33
  - 2.4.2 Software 34
- 2.5 Hydrographic data 35
  - 2.5.1 CTDs on T-PODs 35
  - 2.5.2 Environmental data collection during ship-based surveys 36
- 2.6 Comparison of data derived from T-PODS, visual observations and towed hydrophones 36

3 Results and Discussion 37
- 3.1 Field calibration T-PODS 37
- 3.2 Stationary T-POD data 41
  - 3.2.1 Daily statistics 42
  - 3.2.2 Encounter statistics 44
  - 3.2.3 Encounter rate 46
  - 3.2.4 Baseline data analysis 47
  - 3.2.5 Other sources of variation 51
  - 3.2.6 Power analysis 59
- 3.3 Ship-based surveys 60
  - 3.3.1 Towed Hydrophone 64

4 Conclusion 67
- 4.1 Conclusion of the results 67
- 4.2 Recommendations for set up in T1 69

Literature 71

Appendices

1 Technical Specifications Star –Oddi DST-CTD 75

2 Overview of the status of the T-PODs during the measurements 79

Preface

We would like to thank Cees Minnes of the Directorate North Sea, Nautical Service Den Helder, his co-workers ashore and all the mv. Terschelling crew for their enthusiastic co-operation and assistance, which really contributed greatly to the success of this project. Thanks to everyone who assisted more or less voluntarily on board: Piet-Wim van Leeuwen, Okka Jansen, Christian Hetmank, Jeanne Oudehand, Hans Verdaat, Saskia Mulder and Rob Dekker. Further we owe thanks to Kees Kersting for the help with the CTDs, and to Pam Lindeboom for improving the English text.

The contacts with the successive project supervisors from RIKZ have been constructive throughout the project, which is appreciated.

Summary

In order to evaluate the environmental impacts of the planned Near Shore Wind farm (NSW), a series of baseline studies have been carried out to provide a thorough description of the ecological reference situation. This report describes the results and analyses of the baseline study for harbour porpoises.

Harbour porpoise seasonal presence, density and activity in the study area were measured by acoustic monitoring of echolocation sounds and bi-monthly visual surveys, on two occasions concurrently with towed hydrophone surveys. The monitoring of echolocation sounds consisted of eight permanently deployed acoustic porpoise detectors (T-PODs) operating on a 24 hour basis. The study area encompassed two reference sites and the site where the wind farm is planned.

Due to logistical and technical difficulties, the towed hydrophone survey yielded too little data to enable further statistical analyses. A qualitative observation is that the acoustic recordings did not necessarily coincide with visual observations.

The T-PODs functioned very well and provided a wealth of data, despite the fact that some were removed from their moorings. A strong seasonal variation in relative density became apparent; there were more recordings of harbour porpoises in the fall/winter/spring period compared to the summer months. Spatial variation was also observed, with a slightly higher activity in the northern site of the study area. However, in general, the study site and two control sites did not significantly differ in that respect. Diurnal variation in echolocation activity could be demonstrated in winter months: click frequency was observed to be lower between 12.00 and 16.00 hour and higher at night.
The deployment of T-PODs proved to be a powerful method to collect data on presence and seasonal distribution of harbour porpoises. The outcome of the power analyses with the present set-up in the baseline study is encouraging for the future T_1 study. With 80% significance it will be possible to detect changes in porpoise echolocation behaviour at the 20% level using click intensity and encounter time, and at the 30% and 50% level using respectively click frequency and waiting time.

Ship-based surveys enabled estimations of porpoise density. The survey results also showed a strong seasonal pattern, corroborating the T-POD results. The highest numbers in the study area were found in February, 420 animals uncorrected and 3220 when corrected for animals missed during the survey by the observers.

T-PODs appeared to have a low spatial and high temporal resolution, whereas visual surveys exhibit opposite characteristics. Therefore T-POD deployment and visual survey programs supplement each other well, with almost no redundancy. It is recommended to apply both techniques in the future T_1 study, including some suggestions to optimize data collection.

1 Introduction

1.1 Goal of this study

Dutch government policy aims at realising sustainable energy production in The Netherlands. Offshore wind power is one of the possibility being explored. As a demonstration project, the government has given permission for the construction of a Near Shore Wind Farm (NSW) to be used for assessing both technological and environmental challenges in relation to construction and operation. In order to evaluate environmental impacts from an offshore wind farm it is necessary to carry out a baseline or T_0 study, which provides for a thorough description of the ecological reference (present) situation.

RIKZ has procured a baseline study on the North Sea situation. They have granted a contract (RIKZ-1278) to Alterra to carry out the baseline study for harbour porpoises in the NSW area. In the corresponding document "Terms of Reference Procurement Baseline Studies North Sea Wind Farms", the objectives of Lot 4: Sea Mammals, are explicitly described:

- establishment of occurrence
- establishment of density
- establishment of migration patterns of marine mammals.

The applied techniques to assess numbers and density per species have to be an internationally recognised standard, and should provide data sufficient to describe the reference situation in space and time.

This baseline study includes a description of harbour porpoise seasonal presence, density and activity in the area. The harbour porpoise activity and presence is measured by acoustic monitoring of echolocation sounds, with eight permanently deployed acoustic porpoise detectors (T-PODs) operating on a 24 hour basis, and bi-monthly visual surveys of which some were supplemented by acoustic surveys where a multi-hydrophone array was towed behind a survey vessel.

1.2 Status of the harbour porpoise in the Netherlands

The Harbour porpoise (*Phocoena phocoena*) used to be a common appearance in Dutch coastal waters. Before the 1950s, it was not uncommon to encounter porpoises from the beach, in harbours and even up rivers. The observed numbers started to decline in the second half of the century (van Deinse, 1952, Smeenk, 1987) to such an extent that by the 1970s/1980s porpoise became a rare visitor to the Dutch coast. However, in the early 1990s, live sightings as well as dead strandings started to increase and continue to increase uptill now (Camphuysen, 1994, Reijnders et al., 1996, Witte et al., 1998, Smeenk, 2003).

Whether these fluctuations in observations reflect a real decline and subsequent increase in population or stock size, or may be a result of a shift in coastal distribution, is difficult to say. The assessment of the status of harbour porpoises and trend analyses is virtually impossible due to a lack of systematic sighting schemes. The only available abundance survey is the North Sea wide survey for cetaceans (project SCANS, Hammond et al., 1995). But this is just one survey in time, and has only comparative relevance if it will be followed by another similar survey. However, some quantitative information on coastal abundance has been provided by the systematic "sea-watching" counts carried out by the Dutch Seabird Group. Though initially installed for birds, data on the presence of marine mammals have also been collected since its establishment in 1972. The data are stored in a Marine Mammal Database, which also contains accidental sightings it is regularly updated and can be accessed at http://home.planet.nl/~camphuys/Cetacea.html. It is clear from the data in Figure 1 that the numbers of harbour porpoises observed have increased since the mid 1990s.. The reasons for the noted decline and subsequent increase remain unclear. Possible explanations include changes in prey availability, mortality due to fishing gear, disturbance and pollution. Reijnders has hypothesised that decreased prey availability leading to a shift in distribution and the cumulative effect of accidental catches of porpoises by fisheries may have been the main factors (Reijnders et al., 1996; Reijnders, 1992).

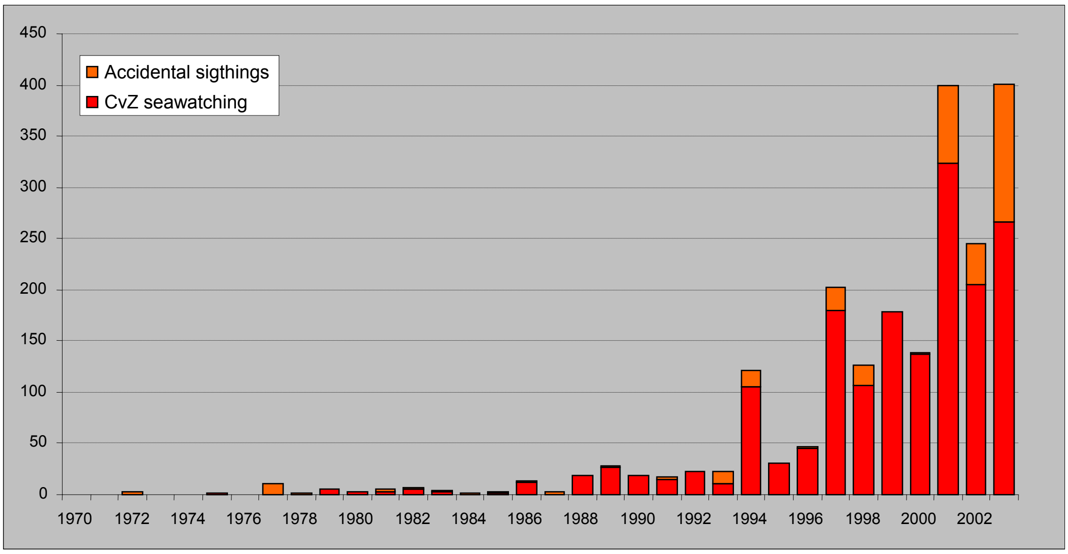


Figure 1. Harbour Porpoises reported from coastal sites since 1970 (Marine Mammal Database, updated 3/1/2004).

Relatively little is known on porpoise biology. Porpoises give birth during summer with a peak in June and mate shortly afterwards; most mature females give birth every year. Live catches in Denmark indicate that the mother and calf stay together for at least a year until the new calf is born and possibly longer. The satellite tagged animals in Danish, Swedish, German, Norwegian and British waters generally move around at a large scale and may swim more than 100 km in one day. In some areas, however, the porpoises may stay within relatively small areas, but these are always related to reefs or narrow straits where concentrations of fish are expected.

In the Netherlands porpoises are seen more frequently in the winter and early spring than in the summer and autumn months (Figure 2).

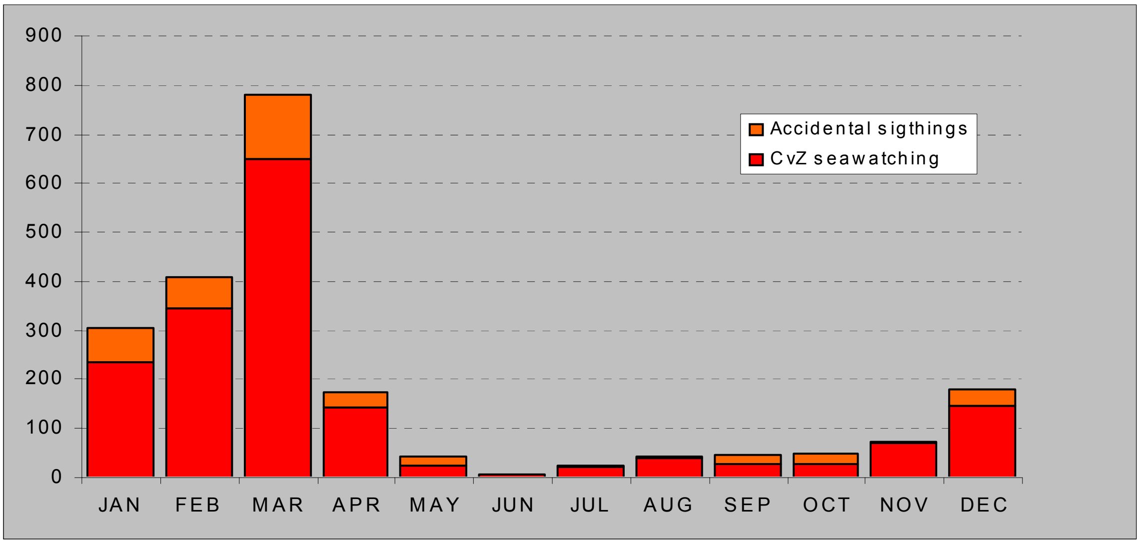


Figure 2 Seasonal pattern in sightings of harbour porpoises in The Netherlands, reported from coastal sites since 1970 (Marine Mammal Database, updated 3/1/2004).

1.3 Choice of methods

Even though porpoises are often seen at sea, the numbers observed are much lower than the actual number present. For this species, telemetry could not be used to meet the objectives of the Terms of Reference, as catching sufficient numbers of porpoises in this area is not realistic. Consequently, other techniques have been proposed.

Firstly, a number of so-called T-PODs (Porpoise Detectors) were deployed, continuously registering the presence of porpoises within the area targeted for the wind farms(NSW) and outside the area at two control sites. This generated a continuous baseline data on the occurrence and seasonal patterns of the animals in the reference situation. This method has proven successful in studies to monitor the effects of wind farms on harbour porpoise in Denmark (Henriksen et al 2003b, Tougaard et al., 2003, Henriksen et al 2004).
Secondly, during six bird surveys (Lot 5: Marine Birds), data on sea mammals were collected by seabird observers on the observation deck. The methods used were in accordance to the internationally accepted monitoring techniques for seabird i.e. strip transect counts (Tasker et al., 1984).

Finally, to estimate the density and presence of porpoises an acoustic detection method was used as described by Berggren et al. (2002) and Gillespie and Chappell (2002). This same method was also in the T-zero surveys carried out the Netherlands in 2002 (Leopold and Camphuysen, 2002) and in Denmark in 2002 (Tougaard et al., 2003). This method consisted of towing hydrophones behind a ship and recording harbour porpoise clicks.

The final analyses cover all the data obtained with these three methods.

2 Methods

2.1 Site description

The study site is located in the North Sea, west of the province of North Holland (The Netherlands), where the planned offshore wind farm (NSW) will be constructed (Figure 3). A total of 8 fixed stations are used for acoustic monitoring of harbour porpoises; three control stations north, three control stations south and two stations within the wind farm area.

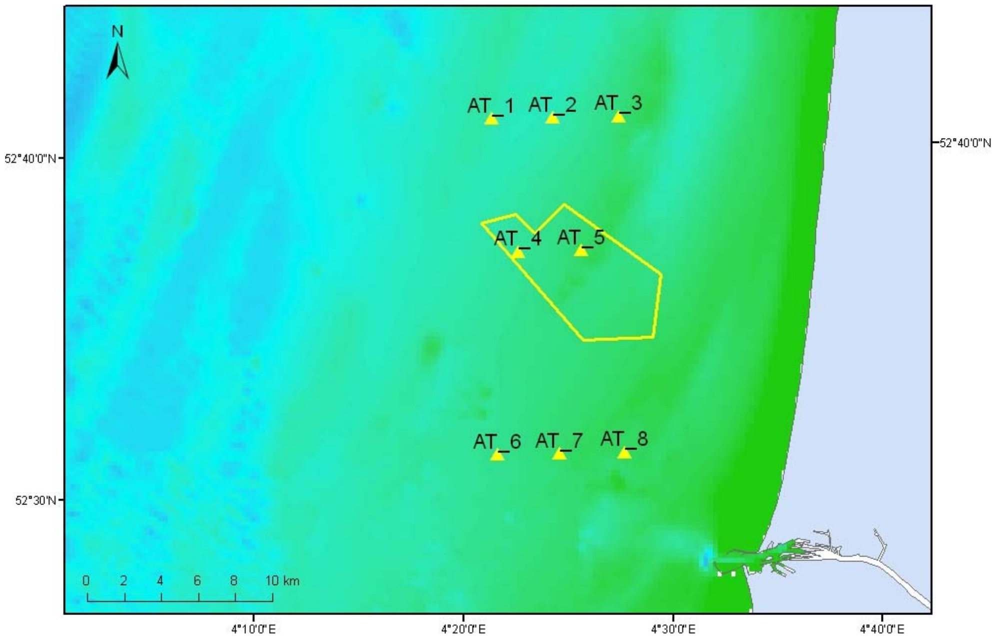


Figure 3. Positions of the 8 monitoring stations (AT1 –AT8), northwest of the harbour of IJmuiden (NL). At the locations AT1 and AT,5 a T-POD equipped with a CTD was deployed. The white line shows the outline of the NSW wind farm area. Geographic system: ED-50; Projection: UTM zone 31N.

The positions of the T-PODs are chosen on the following grounds:

- In the park (NSW): it is very likely that the windmills will be placed in the western (half) part of the envisaged park area. T-PODs have to be placed at least 1 nautical mile or more apart from one another to assure that each T-POD can be considered as an independent recording station, in effect, to avoid that one porpoise is detected simultaneously by 2 neighbouring T-PODs. Two T-PODs (AT4 and AT5) are stationed here.
- Outside the park: based on experience obtained during wind farm studies in Denmark (Teilman et al., 2002b; Henriksen et. al., 2003a), the T-PODs were placed in the two reference areas around 5-6 nautical miles away from the park. This distance should assure reference areas with the same abiotic factors but outside the possible disturbance range from the park. The distance between the T-PODs is the same as for T-PODs inside the park.

- The choice for 3 T-PODs in each of the reference areas (resp. AT1 - AT3 and AT6 - AT8) and 2 in the park is based on the considerations that
    a. only two T-PODs (with the required distance) will fit in the western half part of the park, and
    b. there is a likelihood that one T-POD may get lost due to e.g. fishermen trawling into the buoys. In the event of the latter, the highest priority would be given at maintaining the 2 T-PODs in the park.

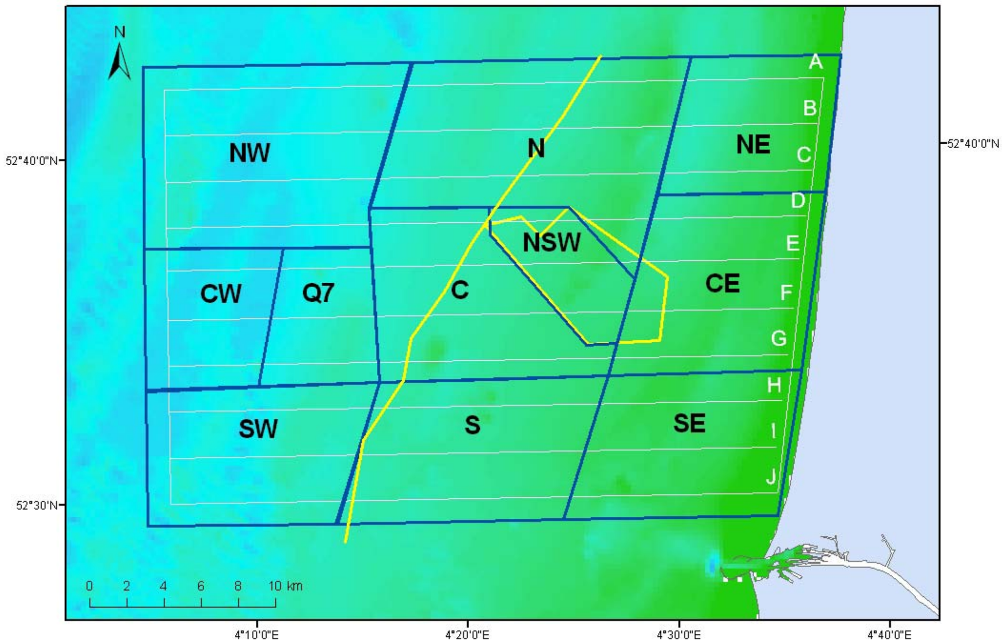


Figure 4. Map of the primary study area (within outer blue contour), with contours of the search area for the offshore wind farm (NSW in yellow polygons), the -20 m isobath used in the distribution models (thick yellow line), the transect lines sailed (white, marked A-J) and the sub-areas used for the RIKZ DONAR Database (blue-lined polygons with black lettering). These sub-areas used as a basis for the estimation of total numbers of birds present in different months. Note that the location, shape and surface area of each DONAR sub-areas is different. Transect lines are represented in white, numbered with capital letters. Geographic system: ED-50; Projection: UTM zone 31N. The surface areas of the DONAR sub-areas are given in Table 1. Surface area (km²)of the Donar sub- areas as referred to in the ship-based surveys.

The T-POD research area coincides partially with the ship-based observations and subsequently the application of the towed hydrophone, which covered a larger area extending further to both the east and west (Figure 4). The ship-based surveys included another intended windmill site, Q7.

Table 1. Surface area (km²) of the Donar sub- areas as referred to in the ship-based surveys.

Donar sub-area	Surface area (km²)
NW	466.86
N	515.31
NE	321.11
CW	287.90
Q7	260.49
C	407.93
NSW	240.35
CE	390.84
SW	378.89
S	405.08
SE	380.29
Total	**4055.05**

2.1.1 Field schedule

The eight T-PODs were regularly serviced. This included cleaning, downloading the data and changing the batteries (Brasseur et al, 2003). Table 2 shows an overview of the fieldwork related to the project. Servicing periods were set to ensure that batteries were changed before drained (about every 100 days).

The visual observations of the porpoises in the area were done in relation to bird-surveys. Typically, the individual surveys were completed within 1 week. Dates were chosen according to important moments in the seabird biology, but also with the expectance of observing marine mammals (paragraph paragraph 2.3)

Table 2. Planned fieldwork in relation to the T-PODs.

Action	**Planning**
First Ship-based survey	September 23-27, 2002
Ship-based survey	October 21, 22, 24, 2002
Ship-based survey	April 07-11, 2003
Ship-based survey	May 19-23, 2003
Calibration of the T-Pods	May 2003
Deployment of T-Pods	June 03-04th, 2003
Ship-based survey	June 23-26, 2003
Ship-based survey	August 11-15, 2003
Servicing of T-Pods, deployment of CTDs	August 26, 2003
Ship-based survey	November 04-07, 2003
Servicing of T-Pods	December 02, 2003
Ship-based survey	February 16-19, 2004
Servicing of T-Pods	March 04, 2004
Retrieval of T-Pods	May 25-26 2004

2.2 T-PODS

In order to observe and quantify the occurrence of porpoises, known to occur in relatively low densities in the study area, it is most suitable to use permanent recording stations such as anchored T-PODs, as well as visual observations which could yield density estimates. T-PODs enable us to record every porpoise encounter within a radius of some hundred meters and, as the stations were monitored for a whole year, seasonality and other variations in occurrence were analysed.

2.2.1 Technical description of T-PODS

The T-POD or POrpoise Detector is a small self-contained data-logger that logs echolocation clicks from harbour porpoises and other cetaceans. It was developed by Nick Tregenza (Chelonia, UK). It is programmable and can be set to specifically detect and record the echolocation signals from harbour porpoises. The T-POD consists of a hydrophone, an amplifier, a number of band-pass filters and a data-logger that logs echolocation click-activity. It processes the recorded signals in real-time and only logs time and duration sounds fulfilling a number of acoustic criteria set by the user. These criteria relate to click-length (duration), frequency distribution and intensity, and are set to match the specific characteristics of echolocation-clicks. The T-POD operates with six separate and individually programmable channels. This allows for e.g. one channel to log low frequency boat activity while the remaining channels log porpoise echolocation activity. All channels had identical settings in this study (Table 3).

The T-POD relies on the highly stereotypical nature of porpoise sonar signals (Au 1993, Au et al. 1999, Diederichs, Grünkorn and Nehls 2003). These are unique in being very short (50-150 microseconds) and containing virtually no energy below 100 kHz. The main part of the energy is in a narrow band 120-150 kHz, which makes the signals ideal for automatic detection. Most other sounds in the sea, with the important exception of echo sounders and boat sonars, are characterised by being more broadband (energy distributed over a wider frequency range), being longer in duration, having peak energy at lower frequencies or combinations of the three.

The actual detection of porpoise signals is performed by comparing signal energy in a narrow filter centred at 130 kHz with another narrow filter centred at 90 kHz. Any signal, which has substantially more energy in the high filter relative to the low and is below 200 microseconds in duration is highly likely to be either a porpoise or a man-made sound (echosounder or boat sonar). This fundamental logic of detection is identical to what is used in the towed array, described below. Although the hardware implementation is different, the fundamental idea is still a comparison between narrow band filters, one low and one high for the T-POD, two low and one high for the towed array. The selectivity of the array for porpoises has been documented in the field by Gillespie and Chappell (2002).

Some spurious clicks of undetermined origin (e.g. background noise, cavitation sounds from high-speed propellers) may also be recorded. These, as well as boat sonars and echo sounders are filtered out off-line in software, by analysing intervals between subsequent clicks. Porpoise click trains are recognisable by a gradual change of click intervals throughout a click sequence, whereas boat sonars and echo sounders have highly regular repetition rates (almost constant click intervals). Clicks of other origin tend to occur at random, thus with highly irregular intervals.

No other cetacean regularly found in the North Sea has sonar signals that can be confused with porpoise signals. Dolphins (with the exception of the genus *Cephalorhynchus*, which does not occur in the North Sea) use broadband sonar clicks, i.e. energy distributed over a wide frequency range, from below 20 kHz to above 200 kHz in some cases. It is thus highly unlikely that they will trigger the T-POD.

Comparison of T-POD recordings with simultaneous visual tracking of porpoises using theodolite show that the effective detection distance is between 100 and 200 meters. Of the 37 animals observed closer than 100 m from the T-POD, 81% were registered by the T-POD. Of the 34 animals that came within 100-200 meters of the T-POD, 31% were recorded by the T-POD (Tougaard et al, *in prep.*).

Table 3. T-POD filter settings used during deployments.

A filter: frequency (kHz)	130
B filter: frequency (kHz)	90
Ratio: A/B	5
A filter: Q (kHz) / integration time	short
B filter: Q (kHz) / integration time	long
Sensitivity:	6
Max number of clicks / scan:	160
Minimum click duration: (μS)	30

Each of the six channels records sequentially for 9 seconds, with 6 seconds per minute assigned for change between channels. This gives an overall duty cycle of 90% (54 seconds per minute), 15% for individual channels (9 seconds per minute). In order to minimise data storage requirements, only the onset time of clicks and their duration are logged. This is done with a resolution of 10 μs. The absolute accuracy of the timing (time since deployment) is much less, due to drift in the T-PODs clock during deployment (a few minutes per month). This drift however, is only of concern when comparing records from two T-PODs deployed simultaneously. Clicks shorter than 10 μs and sounds longer than 2550 μs are discarded.

The hydrophone of the T-POD is cylindrical and thus omni directional in the horizontal plane. Resonance frequency is 120 kHz. T-PODs are insensitive to temperature changes within the normal operating range between 3ºC and 25ºC, except from a reduction in battery life at lower temperatures. Battery voltage does not influence sensitivity as the electronics in the T-POD receive a stable voltage until the battery is drained to 5.1 V, below which the electronics turn off.

The hydrophone, and thus T-POD sensitivity, is insensitive to changes in hydrostatic pressure down to depths of 120 m. The hydrophone ceramics are not expected to loose sensitivity with age beyond a few percent per decade, so for all practical purposes, the sensitivity of a T-POD should not change within its expected lifetime.

The T-PODs used in this study are all version 3, equipped with 32 MB RAM and powered with 99Ah, 7.2V lithium ion batteries (twelve 3.6V D-cells), which gives a maximum theoretical logging period of about 120 days.

Data from the T-POD can be downloaded in the field with a parallel cable for storage on a PC. Data was downloaded with the T-POD.exe program designed for communication with the T-POD and subsequent analysis of data. Figure 5 shows an example of downloaded data. Harbour porpoise echolocation clicks were extracted from the background noise using a filtering algorithm that filters out non-porpoise clicks such as cavitation noise from boat propellers, echo sounder signals and similar high frequency noise. This filter has several classes of confidence of which the second highest class ("cetaceans all") was used. Data were exported in ASCII format for statistical analysis after filtering.

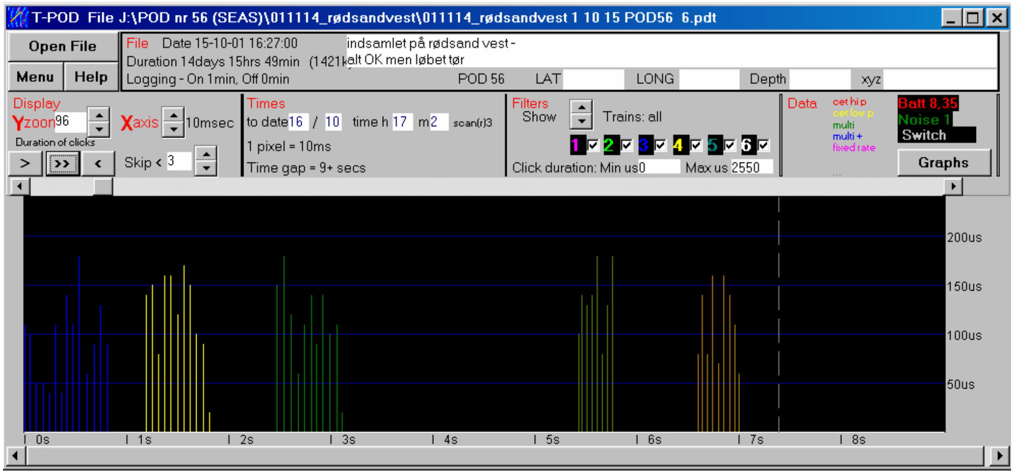


Figure 5. Screen snapshot from the T-POD.exe program. Five series of porpoise clicks can be seen as vertical bars. Time in seconds is shown on the X-axis, and the duration of each click is shown on the Y-axis.

2.2.2 Field calibration of T-PODs

To make sure that the eight T-PODs were working and provided similar results, they were deployed simultaneously in a porpoise-rich area in Denmark prior to the study in the NSW wind farm area. The ninth T-POD (ID no. 276) was not available for the field calibration. The T-PODs were tied to a chain in a line 50 cm apart. This way the T-PODs would have a similar "listening-field". The chain was anchored about 50 meters off the coast at the tip of Fyns Hoved peninsula in Kattegat, Denmark. This area has a high density of harbour porpoises and the animals are regularly observed along the coast close to the shore. The T-PODs were deployed for 19 days (8-26 May 2003) with the same settings as given in Table 3.

Variation among individual T-PODs was taken into account in the design and analysis of T-POD data from the NSW area. A field calibration was performed to assess differences in T-POD sensitivity and test whether the sensitivity changed over time. There were two factors in the field calibration, T-POD sensitivity and time trends, that potentially affected variations in the echolocation activity, as described by the four indicators in Table 4. Temporal variations were described by daily mean levels (*date*, classification variable) or alternatively by a linear trend (*time*, regression variable). Changes in T-POD sensitivity over time were investigated by analysing the interaction of POD-id with temporal variations.

Since click intensity and click frequency are based on one daily value, there is no replication available for combinations of *POD-id* and *date*. Thus, it was not possible to investigate the interaction of those two factors. Changes in the T-POD variation over time was therefore analysed for linear drifts in the sensitivity:

$$\mu = date_i + POD\text{-}id_j + POD\text{-}id_j \times time \qquad \text{(Eq. 6)}$$

There were several observations of encounter duration and waiting time each day in the field calibration, and for these two indicators the following model was employed

$$\mu = date_i + POD\text{-}id_j + POD\text{-}id_j \times date_i \qquad \text{(Eq. 7)}$$

Pair-wise t-tests were carried out to identify the specific T-PODs that were different from the others. Data from the field calibration were analysed using the distributions from Table 4 without an autoregressive co-variance structure. A subsample of 30 encounters were analysed in detail in order to assess differences in the response of the T-Pods to the same signals.

2.2.3 Mooring technique

The mooring used for the T-PODs/CTDs in the Dutch coastal waters was designed using robust material. Where in other areas T-PODs are usually attached to small anchor blocks and small buoys, this study uses very heavy equipment for anchoring the T-PODs/CTDs due to the risk of collision with trawlers in the area. Approximately 15 tonnes of buoys, chain and concrete were used for securely anchoring a single T-POD (Figure 6).

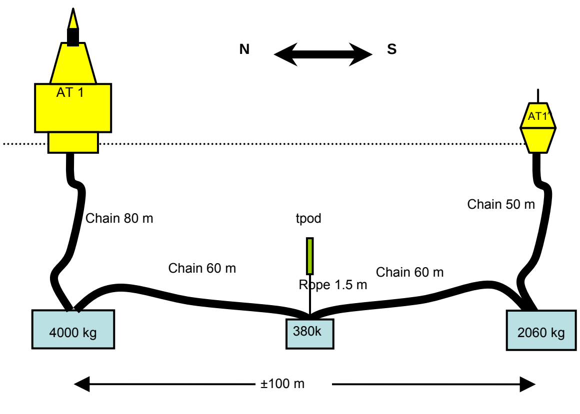


Figure 6. Schematic setup of the T-POD mooring. The large buoy is lighted at night.

Each T-POD is deployed between two large buoys, the larger being equipped with a yellow warning lantern. Furthermore, the experimental setup was regularly announced on VHF-radio by the local authorities.

Figure 7. Set-up of the anchoring. View above water (photo Saskia Mulder, RIKZ)

Figure 8. On board the "Terschelling" it is clear how big the anchoring equipment is. (photo Saskia Mulder, RIKZ)

2.2.4 Analysis of T-POD data

The echolocation activity of harbour porpoises in the NSW area was investigated by means of T-PODs. All deployed T-PODs were version 3 T-PODs, equipped with external transducers/hydrophones. Porpoise clicks were recorded using all channels (1-6, each monitoring 9 seconds every minute) and the average click intensity per minute was calculated as the sum of these 6 channels, adjusted by a factor of 60/54 corresponding to the active "listening" period of the T-PODs. Data retrieved from the T-PODs were stored in a database as 1-minute counts for the 6 separate channels.

2.2.4.1 Echolocation activity indicators

Five indicators were extracted from T-POD recordings stored in the database. The signal, denoted x_t, describes the recorded number of harbour porpoise clicks per minute. It consists of many zero observations (minutes without clicks) and relatively few observations with click recordings. When zero observations comprise a large part of the data set, the data cannot easily be described with a parametric distribution. Therefore the click intensity per minute was aggregated into daily observations of:

$$\textbf{Click frequency}\ (\text{\% minutes with clicks/day}) = \frac{\text{Number of minutes with clicks}}{\text{Total number of minutes}} x100 = \frac{N\{x_t > 0\}}{N_{total}} x100 \quad \text{(Eq. 1)}$$

$$\textbf{Click intensity}\ (\text{clicks per minute/day}) = \frac{1}{N\{x_t > 0\}} \sum_{x_t > 0} x_t \quad \text{(Eq. 2)}$$

Another approach was to consider the recorded click as a point process, i.e. separate events occurring within the monitored time span. Therefore, x_t was considered as a sequence of porpoise encounters within the T-POD range of detection separated by silent periods without any recorded clicks. Porpoise clicks were often recorded in short-term sequences consisting of both minute observations, with and without clicks. Such short-term sequences were considered to belong to the same encounter although there were also silent periods (no minute clicks) within the sequence. We decided to separate encounters from each other when the silent period exceeded 10 minutes. This threshold value was determined from graphical investigation of different x_t-time series. Thus, two click recordings separated by a silent period of 10 minutes or less would still be part of the same encounter, whereas a silent period of 11 minutes or more would act as a separator between encounters. Converting the constant frequency time series into a point process resulted in three additional indicators for porpoise echolocation activity.

Encounter duration = Number of minutes between two silent periods

Waiting time = Number of minutes in a silent period >10 minutes

Encounter frequency = Number of encounters /day

This implied that waiting times had a natural lower boundary of 11 minutes, and that encounters potentially included 1-minute periods without clicks (zero recordings). Encounter duration and waiting times were computed from data from each T-POD deployment period, individually identifying the first and last encounters and the waiting times in-between. Consequently, each deployment period resulted in one more observation of encounter duration, since the silent periods at the beginning and end of each deployment period were truncated (interrupted) observations of waiting times and therefore not used. Encounter duration and waiting time observations were temporally associated with the time of the midpoint observation, i.e. for example, a silent period starting 31 March at 21:09 and ending 1 April at 1:59 was associated with the mean time of 31 March 23:34 and categorised as a March observation.

2.2.4.2 Statistical design and model

Different indicators reflect different features of the same porpoise echolocation activity. Variation in indicators was assumed to be potentially affected by the following factors:

- *Area* (3 levels) describing the general difference between the two control areas (North and South) and the impact area (deterministic main effect).
- *Station (area)* (8 levels) describing the station-specific activity at the different monitoring positions within the two main areas. This factor was modelled as a deterministic effect since echolocation activity was assumed to rely on station-specific features such as depth, bottom topography, sediment type, etc.
- *T-POD id (station area)* (9 levels) describing systematic shifts in the time series recorded at station AT7 resulting from the replacement of a T-POD. Thus, the tests of this effect only relates to differences between the two T-PODs used at this specific station and should not be taken as a general result. The T-POD levels could not be distinguished from the station-specific levels.
- *Month* (12 levels) describing a systematic seasonal change in the activity (deterministic main effect). Temporal variations at a lower scale were considered random.
- *Mont × area* describing differences in the seasonal pattern between the three areas.
- *Month × station (area)* describing differences in the seasonal pattern at stations within the three areas.

If Y describes any of the four indicators and f(Y) is a well-chosen transformation of this indicator described by a suitable statistical distribution with a mean μ and variance σ^2. variations in the mean can then be modelled as a function of all the potential factors given above. However, the two T-PODs at station AT7 recorded data during different months. Consequently, a station-specific seasonal variation cannot be distinguished from the change of T-POD at station AT7, i.e. *POD-id(station area)* and *month × station(area)* cannot be simultaneously included in the model. Therefore, the T-POD specific variation was first investigated assuming a common seasonal pattern for all stations within each of the three areas:

$$\mu = area_i + station_j(area_i) + POD\text{-}id_k\ (station_j\ area_i) + month_l + month_l \times area_i \qquad \text{(Eq. 3)}$$

Then the station-specific seasonal variation was investigated assuming that the change of T-PODs at station AT7 did not introduce a systematic change in the echolocation indicator levels:

$$\mu = area_i + station_j(area_i) + month_l + month_l \times area_i + month_l \times station_j(area_i) \qquad \text{(Eq. 4)}$$

The indices in Eq. (3) and Eq. (4) corresponded to the number of levels for each of the factors given in the list above. Since the two factors, *POD-id (station area)* and *month ×area(station)*, could not be included in one single model, the two different models were compared by means of Akaike's Information Criterion (AIC) (see e.g. Littell et al., 1996).

$$AIC = -2\log(\max likelihood) + 2n_p \quad \text{(Eq. 5)}$$

where log(max likelihood) describes the fit of data and the second term is a penalty function on the number of parameters employed (np is the number of parameters). The smallest AIC indicates the better model.

Transformations, distributions and back-transformations were selected separately for the different indicators by investigating the statistical properties of data (Table 4). The data comprised an unbalanced design, i.e. an uneven number for the different combinations of factors in the model. Arithmetic means by averaging over groups within a given factor do not necessarily reflect the "typical" response of that factor since they do not take other effects into account. Typical responses of the different factors were calculated by marginal means (Searle et al., 1980) where the variation in other factors was taken into account.

Table 4. List of transformation, distributions and back-transformation employed on the four indicators for harbour porpoise echolocation activity.

Indicator	Transformation	Distribution	Back-transformation
Daily intensity	Logarithmic – log(y)	Normal	$\exp(\mu + \sigma^2/2)$ [a]
Daily frequency	Angular – $\sin^{-1}(\sqrt{y})$	Normal	Table 6 (Rohlf & Sokal, 1981)
Encounter duration	Logarithmic – log(y)[b]	Gamma	$\exp(\mu + \sigma^2/2)$ [a]
Waiting time	Logarithmic – log(y-10)	Normal	$\exp(\mu + \sigma^2/2) + 10$[a]

[a] The back-transformation of the logarithmic transformation can be found in McCullagh & Nelder (1989), p. 285.
[b] For encounter duration of exactly 1 minute, 0.2 minute was added before taking the logarithm.

The gamma distribution is used to describe positive observations. Taking the logarithm to durations of 1 minute resulted in zero observations. Therefore, a relatively small value of 0.2 was added to these observations. Because waiting times had a natural lower boundary of 10 minutes imposed by the encounter definition, 10 minutes were therefore subtracted from these observations before taking the logarithm, in order to derive a more typical lognormal distribution. Applying the log-transformation meant that additive factors as described in the equations were multiplicative on the original scale, resulting in the seasonal variation being described by monthly scaling means rather than additive means. Variations in the four indicators were investigated within the framework of generalised linear models (McCullagh and Nelder, 1989). The significance of the different factors in Eq. (3) and Eq. (4) was tested using F-test (type III test) for the normal distribution and log-likelihood ratio test (χ^2-test) for the gamma distribution (SAS Institute, 2003).

For the normal distributed indicators (click intensity, click frequency and waiting time) we included a co-variance structure for the residuals to account for serial correlation, assuming that an observation at a given time was more likely to have a value similar to the previous observation. This implied that there could be some systematic temporal variations in the harbour porpoise echolocation activities at scales less than a month. The co-variance structure was modelled as an ARMA (1,1)-process (Chatfield, 1984) subject to the separate deployment periods, i.e. complete independence was assumed across gaps in the time series. The gamma distribution used for encounter duration and the discrete nature of data (small integer values) did not allow for estimating a co-variance structure for this indicator.

Diurnal variation in the echolocation activity was investigated by calculating mean click frequencies over the 24 hours for each station and month, assuming that the diurnal variation may change with seasons. The potential covariation in echolocation activity due to salinity was investigated by fitting the residuals for each of the four indicators modelled by Eq. (3) versus salinity by means of a non-parametric curve (LOESS, Cleveland and Grosse (1991)). Confidence limits for the LOESS fit were constructed under the assumption of independent residuals, which may not be entirely true given the modelled co-variance structure described above. However, the confidence limits for the LOESS fit serves as an underestimation of the true levels.

2.2.4.3 Determining sample sizes

Sample sizes needed for detecting effects of a specific magnitude can be explicitly predicted for balanced designs if observations are assumed to be normally distributed and independent (Green, 1989). However, such formulas are not readily available for more complex models with an ARMA (1,1) co-variance structure subject to each deployment period. Therefore power calculations in the present study were obtained by simulating a stochastic process to generate data for the indicators and subsequently analyse these simulated data. The model employed included stepwise changes in the impact area during the following monitoring campaign after the baseline (construction and/or operation).

It was assumed that the number of observations for each of the four indicators in a following monitoring campaign (denoted after) would be equivalent to the number of observations obtained during the baseline, i.e. corresponding to a doubling of observations from the baseline. Observations of the four indicators were simulated from a simple model that only described variations between area and periods (baseline versus after).

$$\mu = area_i + period_j + area_i \times period_j \qquad \text{(Eq. 8)}$$

where $period_j$ was a two-level factor (baseline and after) and $area_i$ described variation between the impact area and the two control areas. The interaction, $area_i \times period_j$, described the potential change in the echolocation indicators occurring after the baseline in the impact area relative to the control area (BACI test) and the significance of this interaction will be used for impact assessment. Station-specific, T-POD specific and seasonal variations were not included, since these factors were fixed effects that did not affect the BACI test statistics. Consequently, there was no need to simulate these additional variations, which would complicate the computations.

For the three indicators with a normal distribution, an ARMA (1,1)-process with parameters obtained from modelling Eq. (3) was simulated for separate deployment periods of approximately 2 months. Independent observations were simulated for encounter duration. A relative change of 10%, 20%, 30%, 40% and 50% in the impact area after the baseline was simulated for all four indicators (decline in click intensity, click frequency, encounter duration and increase in waiting time). Batches of 500 simulations for each relative change and each indicator were analysed by the same model (Eq. 8). The number of significant interactions ($area_i \times period_j$) at the 5% significance level out of the total number of simulations provided a power estimate.

2.3 Ship-based surveys

Three different ships were used, the Research Vessels Mitra and Zyrphaea, owned by the Ministry of Transport and Public Works for the two 2002 surveys, and the Orca I, a commercially rented offshore supply vessel. All three ships were approximately 60 m long and their size permitted counting seabirds up to sea stated corresponding to about 6 Beaufort. Ship ground speed was kept at approximately 10 knots, constantly monitored by a portable GPS. Ships positions were logged every 5 minutes and mid-positions of individual 5 minutes were calculated. These were offset by 150 m from the ship's track line to the left and right, for the portside and starboard team, respectively. Porpoises were counted in two (left and right, conditions permitting) or one (left or right) strips adjacent to the ship, following Tasker et al. (1984) and Camphuysen & Garthe (2004). Each recorded porpoise was assigned to a distance class (strip adjacent to the vessel where the animal was first seen). Relative numbers in the strips AB (0-100 m perpendicular), C (100-200m) and D (200-300m) were later used to evaluate missed observations, in relation to perpendicular distance, using the Distance Theory (Buckland et al., 1993).

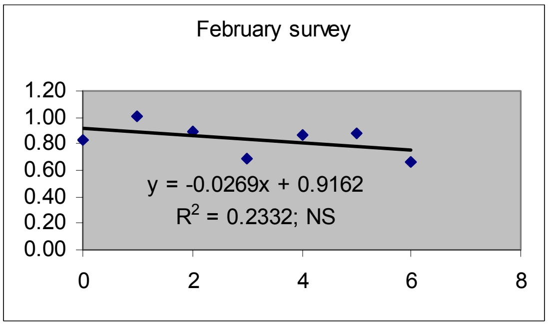
2.3.1 Statistical tests of survey data

2.3.1.1 Resolution and corrections for missed porpoises

The unit for counting, or the counting resolution, was a 5-minute time period. Within this time span, the ship steamed a distance of 1.543 km (at 10 knots). With a standard transect width of 300 m, the surface area observed, on one side of the ship was 0.463 km2. Uncorrected porpoise densities were derived by dividing the sum of all porpoises within the transect band (see Tasker et al., 1984) by this area.

However, in all likelihood some porpoises will have been missed by the observers and the probability of missing porpoises generally increases with increasing perpendicular distance (Buckland et al., 1993). If observations need to be carried out in increasing seas, as in this study in which porpoise counts were merely a by-product of seabird counts, more porpoises will be missed within the counting strips, but the interaction sea state-probability of seeing animals at increasing perpendicular distance needs to be assessed. Other sources of variation include: observer, light conditions, time of day (as a measure of observer alertness), state of the tide (if related to e.g. porpoise feeding or diving/surfacing behaviour), group size and possibly even porpoise density (if related to observer alertness). Therefore, an ideal method should be developed that considers all of these factors. In reality however, such a model is not always feasible, given the available sample sizes. Nor are many sources of variation easily measured or show interactions (e.g. time of day and tidal phase). Therefore, we only checked for a possible influence of sea state on the data, which is on the probability of spotting porpoises at different perpendicular distances. We used the February data set, since this survey yielded the most sightings and was also carried out under a range of sea states. The analyses (Figure 9) give no indication that sea state had a significant influence on the *relative* probability of seeing porpoises at different perpendicular distances as opposed to Teilman (2003). There may of course be a significant effect of sea state on the probability of seeing porpoises anywhere, but this cannot be modelled with the present data.

Seastate	km on effort	n porps seen	n/km
0	6.04	5	0.83
1	24.87	25	1.01
2	67.84	61	0.90
3	27.51	19	0.69
4	74.40	65	0.87
5	38.36	34	0.89
6	3.01	2	0.66



1	30.91	30	0.97
2	67.84	61	0.90
3	27.51	19	0.69
4	74.40	65	0.87
5	41.37	36	0.87

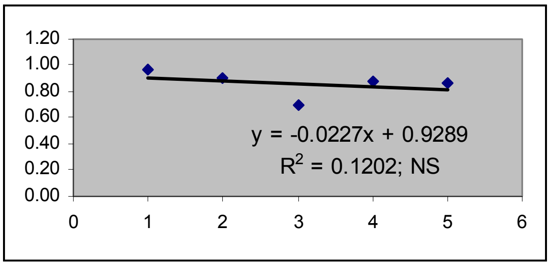


Figure 9. The number of porpoises seen in the February surveys (data from port and starboard combined) at different sea states, with the distance sailed as effort (left). If effort-corrected numbers are regressed against sea state, a non-significant relationship is found (right). As it might be argued that too few data were collected in extreme sea states (0 and 6 Beaufort), these have been combined with the data for the next Beaufort sea state (1 and 5, respectively) in the lower panel, but the relationship remains insignificant.

Correction factors were calculated for observer and perpendicular distance (all sea states combined) by combining all available data per observer team (regardless of trip (month), sea state or whether the observations were made within the primary study area or en route between this area and one of the home ports of the various ships). This was done in order to optimise sample size and was possible because the same principal observer manned the port and starboard side of the ship throughout the surveys. Thusly, the correction factors thus take into account the effect of observer and distance, and are derived by using the relative total numbers of porpoises seen in the equally wide sub-bands AB, C and D; the relative numbers seen in AB, C and D summed, compared to the total numbers seen within 300 m without an assigned sub-band (noted as W); and the relative numbers seen by the "best" team compared to the other team (only paired observations were used, i.e. those counts for which both the port and the starboard team were simultaneously active).

This correction factor is derived as follows (see Figure 10). Combined over the surveys and sea states 0-6 when counts were carried out on both sides of the ship, each observer team watched a total area of strips of 1424 km^2 (equal to total way length sailed when on effort, times the strip width of 300 m). On the starboard side (to the right of the trackline), a total of 191 porpoises were spotted, which would result into a density of 191/1424 = 0.13 animals per km^2. However, from the distribution of sighting on the starboard side (Figure 10) it is clear that many more animals were spotted near the transect line (117 animals in sub-band AB, from 0-100 m perpendicular distance) than in the equally wide bands C (from 100-200 m: 34 animals) and D (from 200-300 m; 40 animals). If we assume that all animals were seen in the first band, then 83 (117-34) and 77 (117-40) animals, respectively, must have been overlooked in bands C and D (with a small complication that 7 animals were seen in "W", anywhere from 0-300 m). Thusly for the starboard side, the density may also be calculated as: (117+34+83+40+77)+7/1424 = 0.25 animals per km^2 (ignoring a correction for the 7 animals seen in W).

A similar argument can be given for the port side observations. From the total numbers of porpoises observed on this side, compared to the total numbers observed at the starboard side, it is clear that more animals were missed at port. This may be corrected by scaling all numbers up to 117 per sub-band (the hatched bars in Figure 10). A simple way of calculating densities would be: ((6*117)+7)/(2*1424) = 0.25 animals per km^2 (over all surveys and sea states). The correction factor $C_{perp,obs}$ for perpendicular distance and observer is: expected numbers divided by numbers actually seen or (sub-units given from left to right as in Figure 10): $C_{perp,obs}$ = (6*117)/(17+10+50+117+34+40) = 2.62. The 7 porpoises seen within 300 of the trackline on the starboard side for which no further information is available may be incorporated as follows: The perpendicular distance (AB or C or D) was known for (191+77) or 196 porpoises, and unknown for 7. Therefore perpendicular distances were known for 96% of all of the porpoises. The best estimate for $C_{perp,obs}$ is: (0.96*2.62)+(1-0.96) = 2.56.

This correction factor $C_{perp,obs}$ only corrects for the effects of perpendicular distance and observer, assuming that all animals present in the nearest sub-band on the side where the best observers watch are actually seen. There is every reason to believe that this was not the case, since animals were clearly missed in all other sub-bands. It is generally accepted that even on zero perpendicular distance, under optimal conditions (sea states 0 and 1) and during dedicated surveys, many porpoises are missed due to their elusive behaviour. The proportion of porpoises missed in sub-band AB by the best observer could not be estimated, as this would have required the simultaneous operation of two observer teams, watching the same strip but at different distances ahead of the ship, as done in the SCANS survey (Hammond et al., 1995, 2002). Two options are open to deal with this problem. We can choose not to correct for the problem that g(0) is less than 1, since we do not know by how much. However, this would clearly result in a negative bias of our estimates of total numbers since g(0) is usually considerably less than 1. Instead, we may consider that only about 1/3 of the porpoises at zero perpendicular distance were detected during the dedicated SCANS porpoise surveys (Hammond et al., 1995, 2002) and adopt this figure in lack of something better.

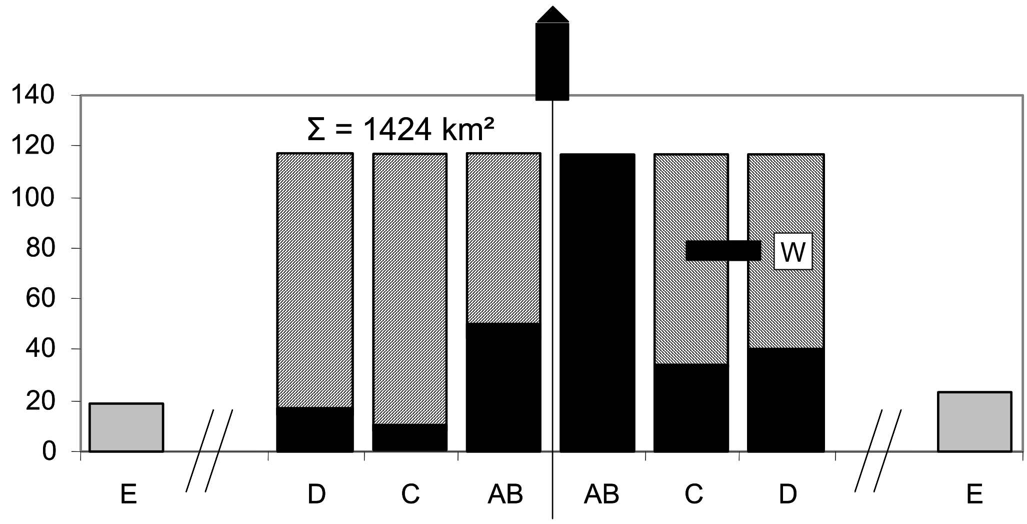


Figure 10. Total number of harbour porpoises seen during all surveys, in all sea states (0-6), while two platforms on port (left) and starboard(right) were manned simultaneously. A total surface area of 1424 km² of strip-transects were watched on each side of the ship. The total number of porpoises seen at either side, per sub-strip of 100 m wide (AB, C and D), are given as black bars; numbers assumed to have been missed, compared to the numbers seen in sub-strip AB on starboard, are superimposed in the barred rectangles. Numbers seen beyond 300 m perpendicular distance (not used in density estimations) are given in grey; numbers seen within 300 m perpendicular distance but without a more precise distance estimation, are given as " W". The ship's course line (0 perpendicular distance) is represented by the central vertical line and ship symbol on top.

If we put g(0) at 0.33, the total overall correction factor for porpoise observations becomes (2.55/0.33)=7.66. In other words, if we accept 0.33 as the best guess for this study, the densities (or total numbers of porpoises present within the study area) as calculated without any correction applied, should be multiplied by 7.66 to get real densities or total numbers.

2.3.1.2 Modelling and analysis of the data

The objective of the statistical analysis of the T_0 data is to give a schematic overview of the distribution pattern of the porpoises per month, in relation to environmental parameters and with emphasis on any conspicuous deviation of porpoise densities in NSW from what can be expected from the general pattern. Any such deviations should be accounted for when analyzing the T_1 data. Any statistical method that allows a patchy geographical distribution will fit the data. No deviating pattern in NSW can be detected in this way. For this reason we developed a model which allows only smooth changes in densities across geographic space. We then investigated whether densities in NSW deviated from what is expected in this smooth model.

The main density trend is expected is with respect to some measure for distance to the coast. Several measurements were available. Note that the Dutch mainland coastline runs more or less from north to south in the study area. True distance to the coast for each count could be calculated, but the X coordinate (Longitude, or Xfield in either RijksDriehoek or UTM coordinate system) could also serve as a proxy. We choose to use the distance from the midpoint of the count to the -20m isobath instead, as this line runs more or less through the middle of the study area and more or less parallel to the coastline, and also parallel to measured gradients in sea surface temperature and salinity.Thus, the distance to this -20 contour joins all other (and highly inter-correlated) information on distance to the coast and gradients in seawater in the area, while also taking into account the slight tilt in orientation with respect to the north-south axis.

In addition a north-south gradient is expected within the study area and has been incorporated into the model by adding the term Y-Field (Latitude in the Dutch RijksDriehoeks coordinate system).

On the basis of these considerations we decided to take distance and Y-Field as the explanatory variables in our basic model, without any interaction effects. We allowed density to chance nonlinearly with distance and Y-Field by using smoothing splines. Our basic model for the density is therefore:

log (expected density) = S(distance) + S(Y-Field)

in which S( ) denotes a spline. The complexity of each of the splines is expressed by the number of degrees of freedom (df). A larger df allows for more flexibility. A spline function with df=1 is identical to a linear model (on log scale) and a spline with df=0 is equal to a model that contains only a constant. The logarithm of density opens up the restricted range of density (non-negative) and makes the expected multiplicative effects of distance and Y-Field on density into additive effects.

This model can be fitted to the count data by the generalized additive model (Hastie and Tibshirani, 1990):

log (expected count) = log(Observed Area) + S(distance) + S(Y-Field) (1)

as log (expected density) = log (expected count/(Observed Area)). The response variable of this regression model contains the observed counts. We assume a generalized Poisson distribution for the counts of which we only specify that its variance is proportional to its expected value. The proportionality constant is called the dispersion parameter. It is equal to 1 for Poissonian data and >1 for overdispersed data. The dispersion parameter is estimated from the Pearson statistic, and set to 1 if the estimate is smaller than 1 since underdispersion is extremely unlikely for these data. We also tried to fit the model with the alternative assumption that the data are negative binomial (a common model for clustered data) but this attempt failed due to numerical problems (nonconvergence). The calculations were carried out with Genstat Committee (2002).

The degree of freedom (df) of each spline was determined by backward selection, starting at df = 4 for each predictor, and decreasing first the degrees of freedom for distance and then decreasing the degrees of freedom for Y-Field. The decrease in df continued for as long as it did not lead to a model that was significantly worse than the model from which the degree was dropped. Significance was judged by an F-test with P = 0.05 (5% significance level) and the dispersion parameter as denominator
The so final model obtained this way was used to predict bird density at each point of a 250 x250 m grid, covering the total primary study area. Deviation of the observed densities in NSW from the model was examined by adding the term NSW to model (1):

log (expected count) = log(Observed Area) + S(distance) + S(Y-Field) + b*NSW

in which NSW = 1 if the data point was within the NSW contour (Figure 3) and 0 elsewhere and b is a regression coefficient. The significance of the extra term was examined with the above F-test. The ratio of the density in NSW or Q7 and the density as expected by model (1) is estimated by exp(b) [denoted as factorNSW in Table 3 which also shows the 95% confidence intervals for lfactor and ufactor, calculated on the basis of the standard error of b (se_b)].

From the standardized residuals of the model with 4 df for distance en Y-Field, the autocorrelation was calculated between consecutive observation times and the spatial autocorrelation. The spatial autocorrelation was expressed as the semi-variance of observations taken with 1000m. (vario1_2). The spatial correlation is low if this semivariance is close to or greater than 1.

No significant difference was found between the densities in NSW and those expected by our smooth model in three cases.

2.4 Computerised Passive Acoustic Detection (Towed Hydrophones)

A towed stereo high frequency hydrophone and computerised porpoise detection and tracking system were available for these cruises. This was based on the equipment and software developed by (Chappell et al., 1996) and further refined by (Gillespie and Chappell, 2002). The hydrophone is towed from the vessel in use for the visual survey and registers high frequency clicks and their bearings. The spectral content and envelope shape of detected clicks and patterns of bearings are useful for distinguishing porpoise clicks from other noise sources. Patterns of change in bearing provide a further confirmation of porpoise detections and an estimate of the range to the animals as they come abeam. When used in this way from the visual platform it provides a number of pieces of additional information and enhancements. It provides an independent source of harbour porpoise detections that can be compared with visual detections to estimate the proportion of animals that each techniques fails to detect (e.g. Buckland, 1996). Some investigations are underway on adapting mark recapture methods (e.g. Borchers et al., 1998) to make better use of such data and may be applied in a subsequent T_1 study. Acoustic detections have been shown to be less affected by poor sighting conditions and high sea states, allowing the survey to continue in poor weather and conducted throughout the night as well.

2.4.1 Hydrophone and Analogue Electronics Module

The porpoise detection system used in the survey can be considered to consist of three components. A stereo towed hydrophone, a multichannel analogue envelope tracing unit and a multichannel digitising card with software running on a PC.

The hydrophone streamer comprised two HS150 ball hydrophone elements with a nominal sensitivity of -204dB re.1V/μPa. The spacing between the two hydrophone elements was 3m. Each element was connected to a preamplifier with a gain of 40dB and had output circuitry suitable for driving 75Ω coaxial cable. The streamer was towed some 100m behind the research vessel on strengthened cable. A long tow cable served to keep the hydrophones some distance from major sources of noise, such as the propeller, and out of the vessel's wake.

Porpoise vocalisations consist of trains of distinctive narrow band ultrasonic pulses with most energy being found between 120 and 140kHz. As it is not practical to digitise and analyse multiple channels at harbour porpoise frequencies (>120kHz) in real time on an affordable laptop computer, envelope-tracing circuitry, implemented in analogue electronics, was used to convert the high frequency clicks to simpler, lower frequency wave forms that could be readily digitised and analysed in real time. Spectral information was provided by filtering the incoming signal into three frequency bands, one covering the band in which porpoises are known to vocalise - the 'porpoise band' (centred on 125kHz) and two 'control bands' at lower frequencies (50 and 75Khz). By comparing amplitudes within these three bands it was possible to discriminate between the narrow band porpoise clicks and broad band noise. Typical sources of broad band noise include shrimps, cavitating propellers, bottom noise and the clicks of many delphinid species. The output from each filter was connected to an envelope-tracing circuit and logarithmic amplifier. An active full wave rectifier circuit was used to minimise diode voltage drop. The rectifier was followed by a logarithmic amplifier and a second order low pass filter designed to smooth the output of the envelope tracing circuit.

Signals at the outputs of all three envelope-tracing circuits for the front hydrophone and the porpoise channel alone for the rear hydrophone were digitised at a sample rate of 25kHz using a 12 bit DAS16/300 Computerboards™ ADC (analogue to digital converter) board.

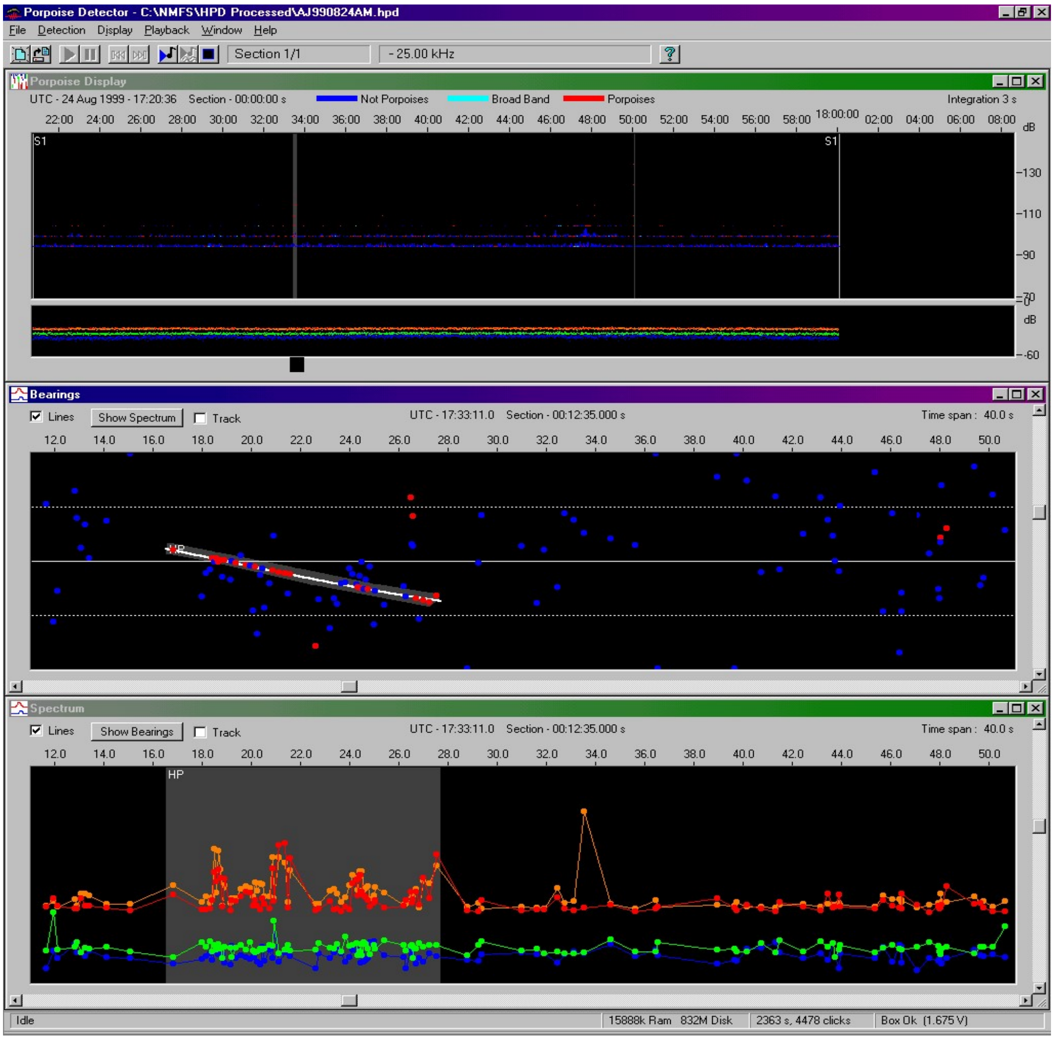


Figure 11. The analysis window in the 'Porpoise' program showing three data display windows. 'Traditional' display (top), time bearing display (middle) and spectral display (bottom).

2.4.2 Software

The "Porpoise" computer program (written by Douglas Gillespie and available from IFAW) was run continuously to collect and display data. "Porpoise" detects transients in the digitised envelope-traced channels, displays them in real time and stores their smoothed rectified wave forms in files for later analysis. Porpoise is also used to analyse these files offline after surveys have been completed in order to locate and mark likely porpoise events. Summary data from these marked events are then exported to an Access database.

There are several steps in identifying a likely porpoise event. The fist is the removal of non-coherent noise. The "Porpoise" program discards any transient that trigger on one channel which do not have a corresponding trigger within the maximum time delay between the channels (determined by hydrophone spacing and the speed of sound). The logic there is that such transients cannot have been caused by a significant far field sound source (they may be due to electrical noise or events such as cavitations close to only one element). This has proven very effective in removing a great deal of noise from files.

The next stop is to assign clicks to three classes, probable porpoise (coloured red) and broad band or "non-porpoise" clicks (coloured blue), based on the relative energy levels within the three bands. Porpoise clicks, of course, have relatively high levels within the porpoise band. The rules used to assign clicks in this way were derived empirically from data files collected on previous surveys.

The final step is manual detection. An operator views summary plots of stored data (top pane Figure 11) and investigates potential porpoise events (e.g. clusters of red detections). Further discrimination of individual clicks can be made by investigating relative levels in the three bands (bottom pane Figure 11) and also examining the traced wave forms of each click (see window Figure 30). A final, and perhaps the most useful, indication of a porpoise detection is that the porpoise clicks should be on a consistent bearing, changing steadily from ahead to astern as the boat moves past the pod of porpoises (see middle pane Figure 11).

Once identified, events are marked with a bounding line, using a mouse, and a summary of all clicks within the event are then extracted and stored in an Access database. In addition, a line is fit to the porpoise clicks within the event, from which a time and distance abeam is calculated, using target motion analysis and assuming the porpoise pod is stationary.

2.5 Hydrographic data

2.5.1 CTDs on T-PODs

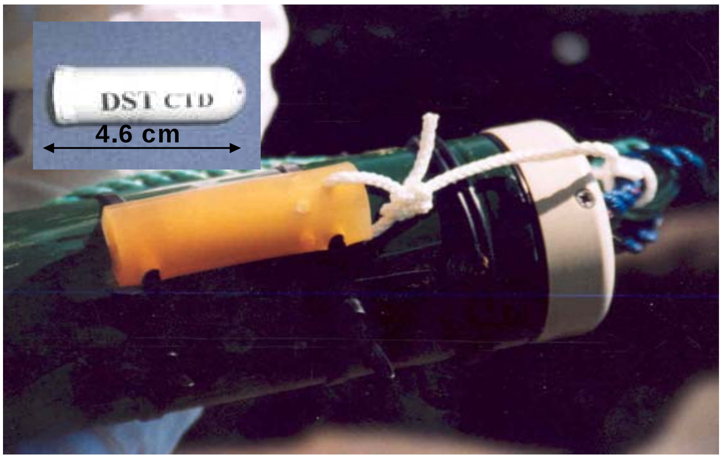


Figure 12. Attachment of one of the CTDs to a T-POD

It is likely that the salinity along the Dutch coast varies quite a bit, as a result of the salt water (app. 35 ‰) coming from the Channel (southwest) and freshwater from the River Rhine (southeast). The bodies of water meet along the Dutch coast, only to mix north of the Frisian Islands (Visser et al., 1994). Based on studies in the German Bight (Teilmann et al., 2002b), it is expected that the hydrographical loggers will increase the power of the data significantly, as the signal of hydrographical variation in the density variation of the porpoises will be greater than the variation due to windmills. This study provides information on the salinity using two CTDs are deployed along with the T-PODs.

The 2 CTDs used were Star–Oddi DST-CTD recording temperature, pressure and conductivity (technical references are found in appendix 1). They were set to log every 15 min. Because of their small size (4.6 cm long and 1 cm wide) they could be attached directly to the T-PODs (Figure 12.). The final contract for this study was delayed, resulting in a very short preparation phase. Since the delivery time of the CTDs did not coincide with the initial deployment of the T-PODs it was only possible to deploy them during the 1st servicing. Therefore salinity data are not available for the first period.

2.5.2 Environmental data collection during ship-based surveys

Each individual count was characterised in space by: geographical position (X,Y), water depth (taken from the GIS data file tnodiepte100 that has water depths for the area on a 100x100 m grid size with a resolution of 0.1 m); and the distance to the major -20 m isobath. Additional information on actual sea surface temperature and salinity were collected during five of the eight surveys but these obviously differed between surveys and also showed some missing data. These data are fully reported in Leopold et al. (2004).

2.6 Comparison of data derived from T-PODS, visual observations and towed hydrophones

Extensive quantitative comparison of the T-PODs and more widespread observation methods (ship-based observations) is beyond the scope of this study. It is important to stress that monitoring programs using T-PODs and survey programs in some sense are orthogonal investigations that supplement each other well and with almost no redundancy. Surveys thus have high spatial resolution, but poor temporal resolution, whereas the situation is exactly the opposite for T-PODs (low spatial and very high temporal resolution). Moreover, it must be considered that levels (densities) at which porpoises are present in the Dutch waters are relatively low, especially in the summer when most overlap between the methods occurred (Table 2). Ideally, this comparison should be done in an area of high concentrations. Therefore in this report we therefore will compare the data qualitatively, looking for similar trends during seasons and in geographical terms.

3 Results and Discussion

3.1 Field calibration T-PODS

Field calibrations showed that all T-PODs were working and with the exception of POD239, they had comparable, although not identical sensitivities. A representative selection of 3 out of 19 days of data from the field calibrations at Fyns Hoved in Denmark is shown in Figure 13. It can be seen that all of the T-PODs detect the majority of harbour porpoise encounters. No systematic pattern is seen between T-PODs where some units recorded all encounters and others recorded only a few. POD239 is the exception for, missing a substantial number of the encounters recorded by the other seven PODs. The average levels of the four indicators were also comparable over the entire 19-day period, again with the exception of POD 239 that appeared to record substantially lower echolocation activity (Table 5). POD239 recorded 264 encounters in total, while the other T-PODs recorded between 315 and 391 encounters. Results of the statistical test of recordings from the eight T-PODs are shown in Table 6.

Table 5. The number of observations and averages for the four echolocation activity indicators from the eight T-PODs deployed during the field calibration at Fyns Hoved.

T-POD ID	Station	Daily statistics			Encounter statistics		
		No. of obs	Intensity	Frequency	No. of obs	Duration	Waiting time
230	AT6	19	44.3	3.00%	365	3.86	66.7
231	AT7	19	44.6	2.56%	315	3.91	77.9
232	AT8	19	44.6	2.82%	356	3.76	68.5
233	AT3	19	40.5	2.54%	347	3.10	71.1
234	AT5	19	41.7	2.84%	363	3.69	67.2
238	AT1	19	41.0	3.47%	391	4.68	61.0
239	AT2	19	33.4	1.63%	264	2.47	95.1
240	AT4	19	38.5	2.57%	349	3.38	70.2

There were significant differences between T-PODs in all four indicators (Table 6). T-POD239 recorded relatively lower echolocation activity than the other T-PODs and the mean value for this T-POD was significantly different from all the other T-PODs for all indicators. However, the p-values in Table 6 changed only marginally for 3 of the 4 indicators, when data from this specific T-POD was not included ($p=0.0007$, $p<0.0001$, $p=0.0016$ for click intensity, click frequency and encounter duration, respectively). For the fourth indicator, waiting time, the 7 remaining T-PODs had similar mean levels ($p=0.1736$). Although the mean values from all the T-PODs were within a reasonable range, there were significant differences in the loggings between several of the T-PODs.

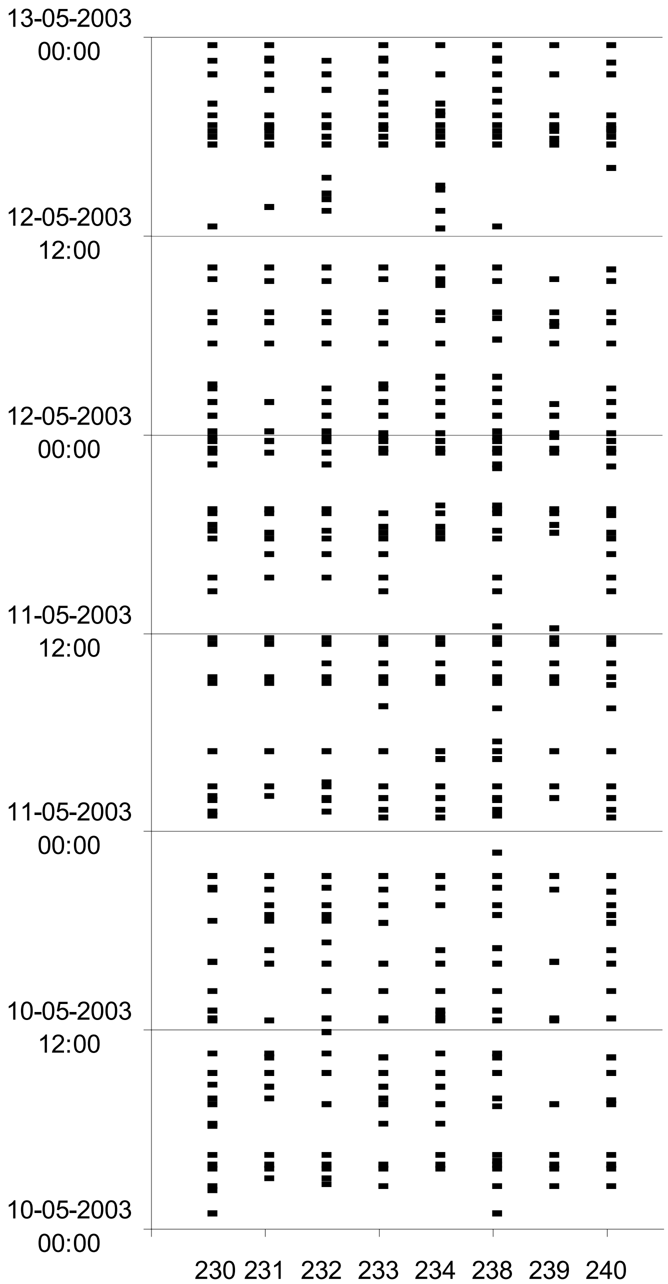


Figure 13. Visualization of encounters recorded the eight T-PODs during 3 of the 17 days of field calibration. Each dot indicates the starting time of an encounter. T-POD numbers are shown on the x-axis.

These differences could be due to several factors:

1) Missed signals when the T-PODs change from one channel to the other, missing one second of recordings every 10 seconds. This gap in data logging is not synchronised between T-PODs and will inevitably result in different clicks being lost on different T-PODs.
2) The highly directional echolocation signals may result in some click encounters only being recorded by some T-PODs in the line.

3) Differences in sensitivity between T-PODs. When fewer and shorter encounters are recorded by one T-POD over a longer period, in the case of POD 239, this is most likely due to of a lower acoustic sensitivity in the particular T-POD.

Table 6. Analysis of T-POD specific variation for data recorded during the field calibration. Significance levels were tested using an F-test for click intensity, click frequency and waiting time, while a $\chi 2$ was used for encounter duration. DF=degrees of freedom, Den=denominator, p=probability.

Indicator	Factor	Number DF	Den DF	F-test or χ^2-test	p
Daily click intensity	*POD-id*	7	119	9.95	<0.0001
	date	18	119	19.15	<0.0001
	POD-id×time	7	119	1.47	0.1830
Daily click frequency	*POD-id*	7	119	19.48	<0.0001
	date	18	119	15.86	<0.0001
	POD-id×time	7	119	0.20	0.9853
Encounter duration	*POD-id*	7		39.99	<0.0001
	date	18		127.17	<0.0001
	POD-id×date	126		85.58	0.9978
Waiting time	*POD-id*	7	2590	3.62	0.0007
	date	18	2590	6.31	<0.0001
	POD-id×date	126	2590	0.34	0.9333

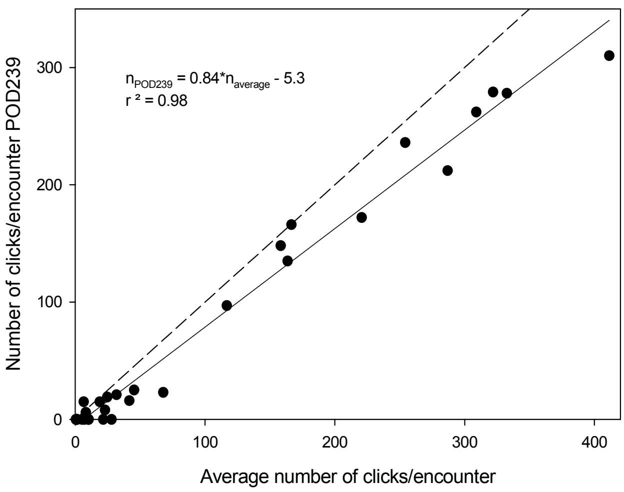


Figure 14. Relationship between number of clicks per encounter recorded on POD239 and the average number recorded on the seven other PODs. Data from the first 30 encounters. Broken line is 1:1 correspondence, solid line is best fitting straight line.

Figure 14 shows the number of clicks recorded by POD239 for the first 30 encounters of the calibration period, compared to the average number of clicks recorded by the seven other T-PODs during the same 30 encounters. There is a very strong correlation between the recordings, but it also shows that during these encounters POD239 only recorded on average of 84% of the clicks recorded by the other PODs, consistent with a lower sensitivity.

The significant variation between T-PODs was accounted for in the design by keeping the T-PODs at the same position throughout the monitoring period.

Therefore the T-POD specific variation will not influence the results of the baseline program. A very important result of the field calibration study was that the encounter duration and waiting time showed no change over time (*POD-id* × *time* not significant) and similarly, daily click intensity and frequency did not reflect any T-POD specific linear trends. This shows that the T-PODs did not change their sensitivity over the 19 days of field calibration.

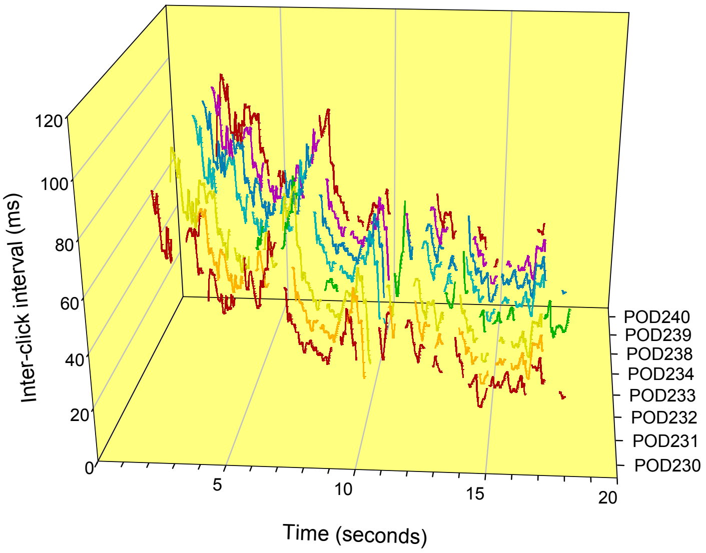


Figure 15. Comparison of recordings of the same encounter on the eight PODs. Lines show inter-click intervals (time from previous click). Gaps in lines indicate inter-click intervals above 100 ms. Differences in clock drift between T-PODs were compensated by adjusting sequences on the time scale to obtain best correspondence.

Figure 15 and Figure 16 show a detailed analysis of the recordings by the T-PODs during a single click sequence (duration approx. 18 seconds), which formed the main part of an encounter. Figure 15 shows variation in the inter-click intervals during the click sequence, as seen by the eight PODs. Several points are apparent from the figure. First of all the close almost exact correspondence between recordings, which proves that the recordings are from the same sound source and not internal noise or local sound sources in the immediate vicinity of the PODs. Secondly, the shape of the curves and the inter-click interval ranges observed are consistent with what would be expected from harbour porpoise echolocation signals (Teilmann et al., 2002a). Several gaps are visible in the curves. Some are only apparent in single traces and are likely to be due to the change from one listening channel to another. Other gaps are seen on all or most recordings. These may be due to genuine pauses in the echolocation activity of the porpoise or that the pod directs its beam away from the array for a short time. The latter is probably the explanation why POD 233 (green trace) records substantially fewer clicks than the rest in this sequence. This T-POD was the outermost in the line and may have been outside the sound beam from the porpoise for a longer time than the rest. This T-POD did not record significantly fewer clicks than the others in the overall test of sensitivity. Figure 16 shows the distribution of click durations, as recorded by the eight T-PODs during the sequence shown in Figure 15. The click durations are also fully consistent with what is expected for porpoise clicks, which have maximum durations up to 150 μs. As the T-

POD can only record the part of the signal which is above the detection threshold, recorded click durations will inevitably be somewhat shorter. It is noteworthy that click durations recorded are very similar for all PODs, except for POD 239, which recorded substantially lower click durations. This is another indication that the sensitivity of this T-POD is lower than the seven other PODs, resulting in the part of the porpoise signals above the threshold being shorter than by the others. It should also be noted that click durations recorded by POD233 are in line with the others (except 239), further supporting the suggestion above that this T-POD was ensonified to a lesser degree than the other seven T-PODs during this particular encounter.

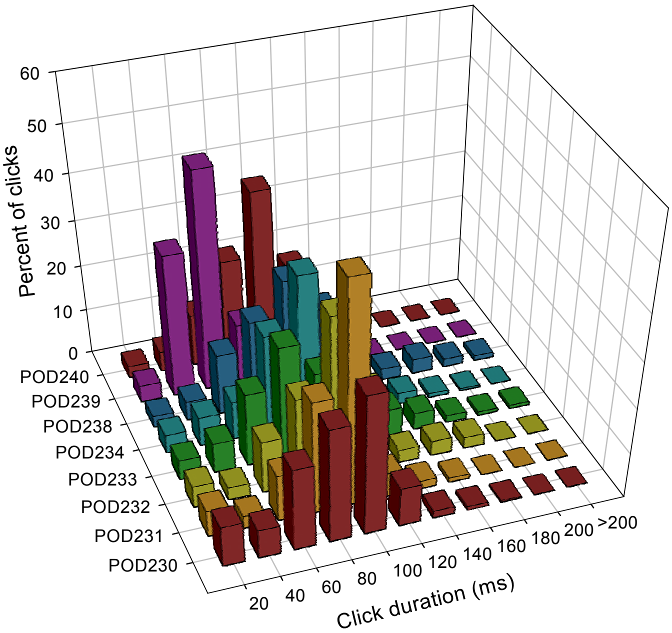


Figure 16. Duration of clicks recorded on the eight T-PODs during the sequence shown in Figure 15.

3.2 Stationary T-POD data

T-PODs were deployed at all 8 stations in the NSW area in June 2003. The time series contains some gaps resulting from technical problems with the T-PODs, detachment from the mooring and loss of T-PODs (see appendix 2 for an overview of the deployment schedule of the T-PODs). The T-PODs were deployed at the same positions throughout the entire study. At one station, AT7, the first T-POD was lost and replaced by a new T-POD with identical specifications. The T-PODs and all associated gear were recovered in May 2004, marking the end of the baseline period. Thus, the baseline period stretches over 12 months. Daily and encounter statistics were extracted from minute recordings stored in the database.

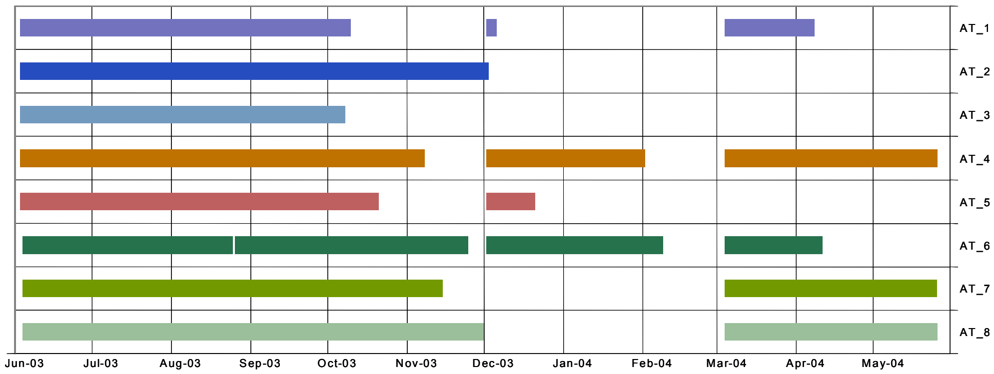
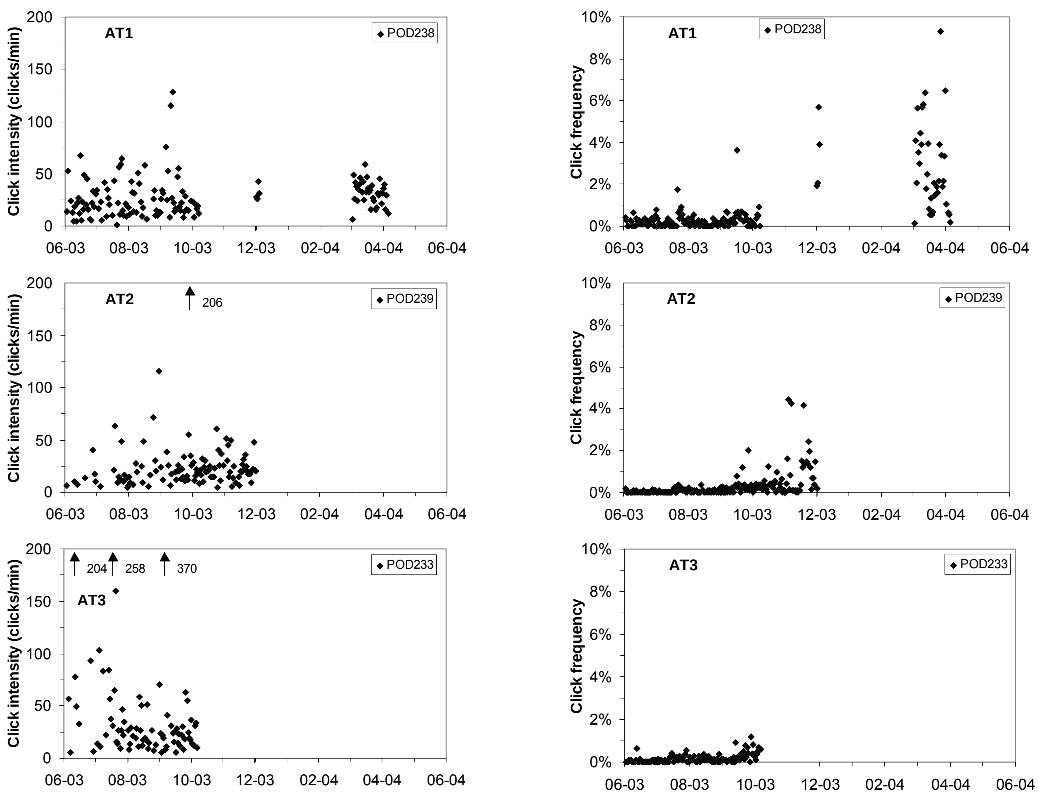


Figure 17. Functioning of the T-PODs: coloured bars indicate when data was collected by the different T-PODs (AT1-AT8). Lack of data was mainly due to the (temporary) loss of the POD (see appendix 2).

3.2.1 Daily statistics

Daily click frequencies and intensities were calculated from the T-POD data (Figure 18). There was a total of 1730 days of T-POD monitoring data from the 8 positions, with 168, 183, 127, 303, 159, 280, 247, and 263 days at station AT1-AT8, respectively. Click intensities could not be calculated for 473 monitoring days (~27%) due to no click recordings, i.e. these corresponded to zero click frequency. All stations appear to have a reasonable amount of data, although stations AT2 and AT3 only have data from the first 6 months.



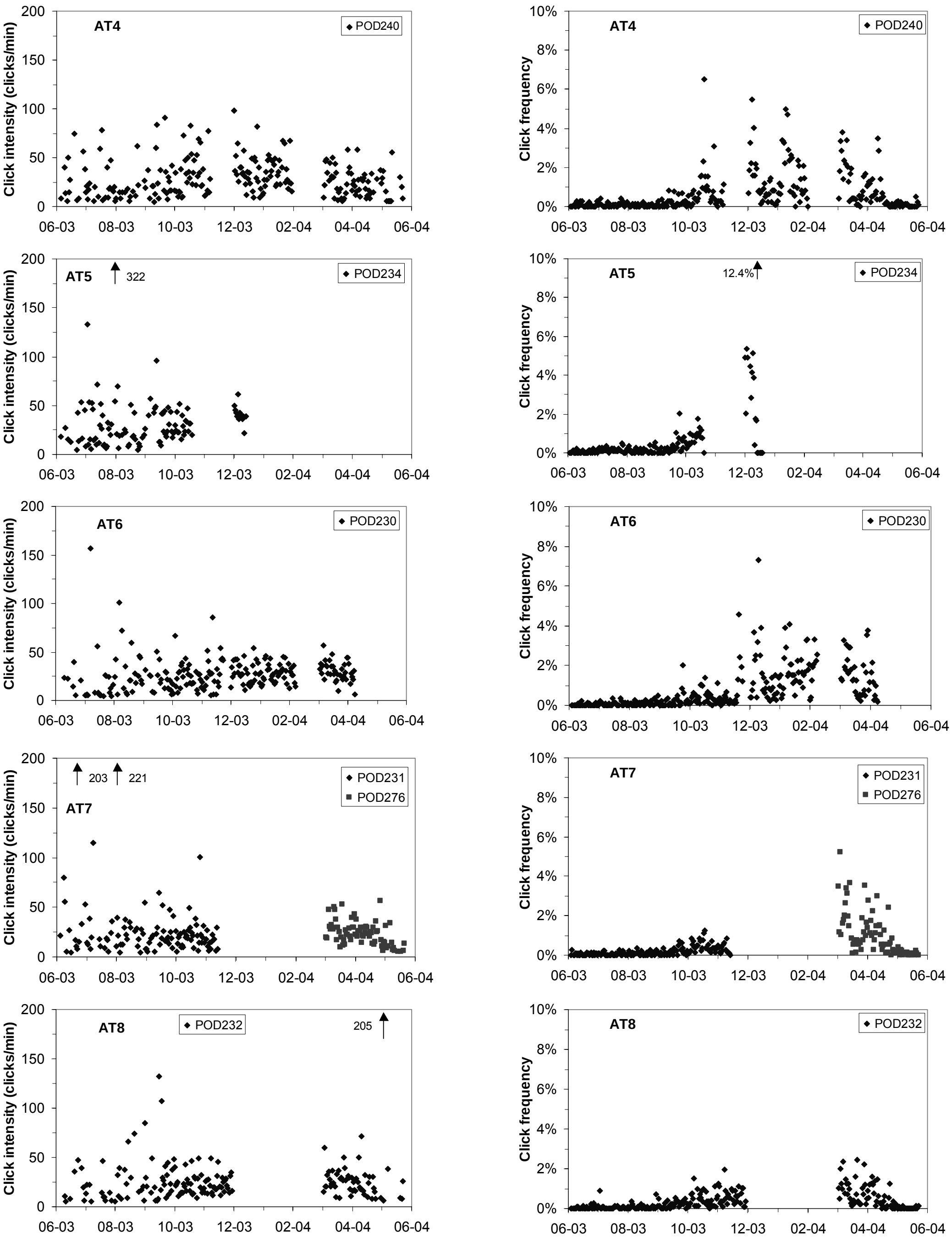


Figure 18. Daily click intensity (left panel) and click frequency (right panel) extracted from T-POD data collected at NSW from June 3 2003 to May 25 2004. Eight daily click intensities and one daily frequency exceeded the plotting range as indicated by arrows and corresponding values.

The average daily click intensity varied from 24.1 to 39.9 clicks per minute at the 8 stations without any specific spatial trend. The average click frequency varied from 0.15% at station AT3 to 0.87% at station AT1, although it should be acknowledged that deployment periods differed between stations. The average click intensity was relatively constant over the period, whereas the average click frequency had a pronounced pattern with low values of approximately 0.1% in summer (May-August) increasing to approximately 1.5% in winter (December-March) (Figure 19). The relatively high average click intensity at station AT3 for June, July and August were due to three extreme observations in each of these months (see Figure 18). Monthly averages for June and July at stations AT5 and AT7 were also affected by single observations with daily click intensities above 200 clicks/min. Similarly, the low click frequency average for February at station AT4 was based on a single observation.

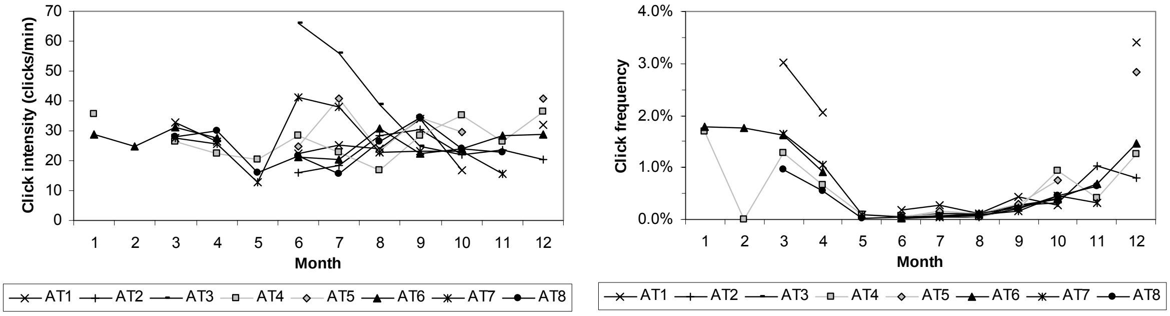
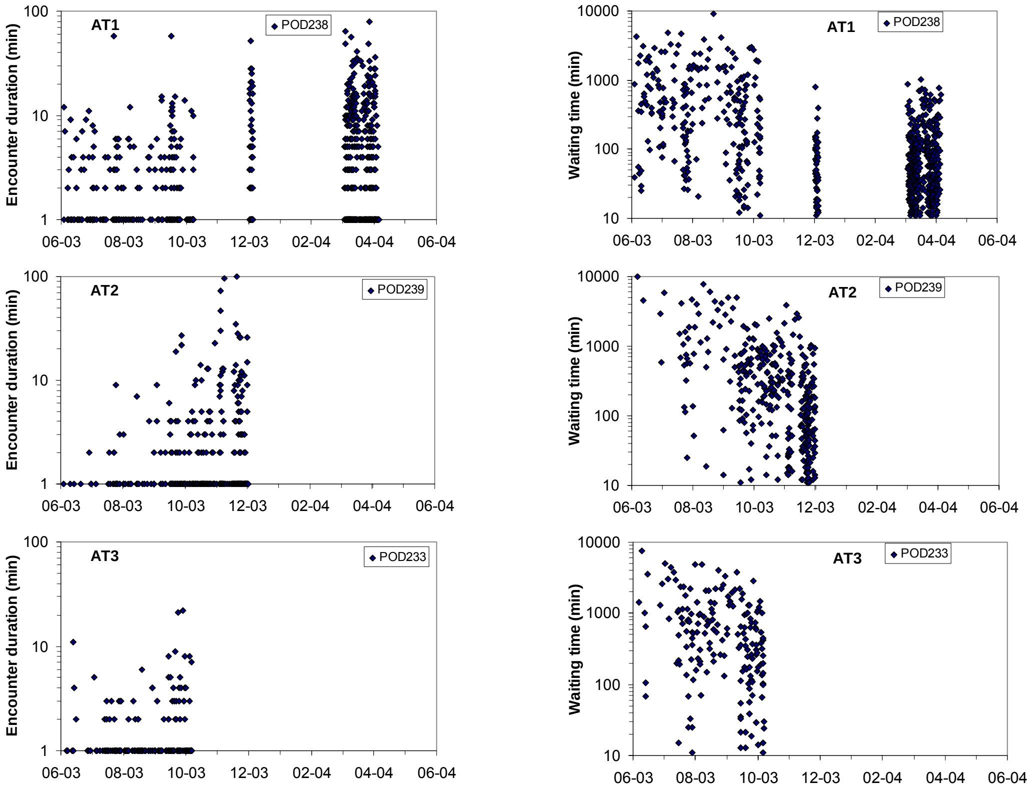


Figure 19. Monthly averages of daily click intensity (left) and frequency (right) for the 8 stations. The two stations in the impact area (AT4 and AT5) are marked by grey-shaded symbols and connected with grey lines.

3.2.2 Encounter statistics



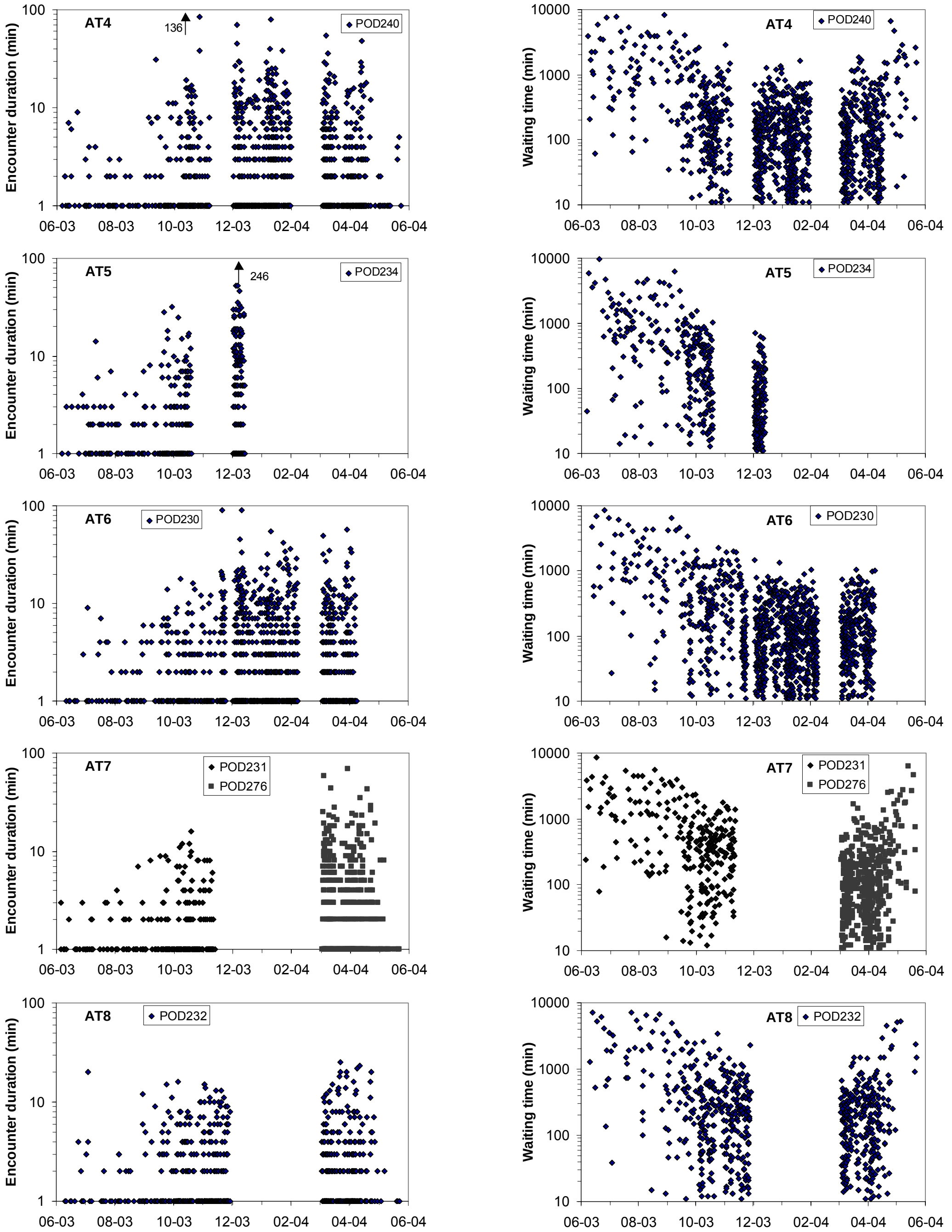


Figure 20. Encounter duration (left panel) and waiting time (right panel) extracted from T-POD data collected at NSW during June 3rd 2003 to May 25th 2004. Two encounter observations and nine waiting times (not shown) exceeded the plotting range. Note the log-scale on the y-axis.

Encounter duration (n=5518) and waiting time between encounters (n=5500) were calculated from the T-POD data (Figure 20). The lowest number of encounters were observed at Station AT3 (n=183) and the highest number at Station AT6 (n=1281). Inevitably there were fewer waiting times than encounters since the first and last silent period of each separate T-POD recording were excluded from the analysis.

The average encounter duration was relatively short, approximately 2 minutes, in summer (May-August) increasing to 4-6 minutes in winter and early spring (November-April). Waiting times showed the reverse pattern with an average above 1 day between encounters in summer (May-August) and 2-2.5 hours in winter (December-March). The seasonal patterns were clearly visible at all stations (Figure 21).

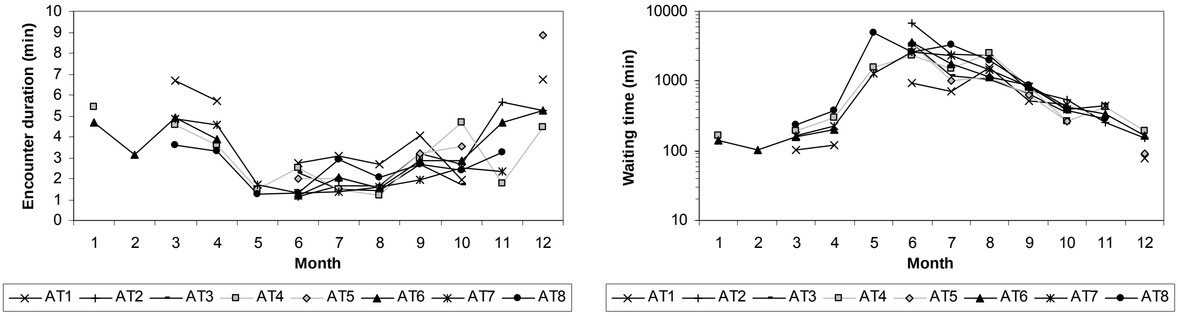


Figure 21. Monthly averages of encounter duration (left) and waiting time (right) for the 8 stations. The two stations in the impact area (AT4 and AT5) are marked by grey-shaded symbols and connected with grey lines. Note the logarithmic scale for waiting times.

3.2.3 Encounter rate

The daily number of encounters (encounter rate) is a much coarser measure. In Figure 22, the encounter rate is averaged per month to give an overview of the seasonal and geographical variations in the porpoise acoustic activity.

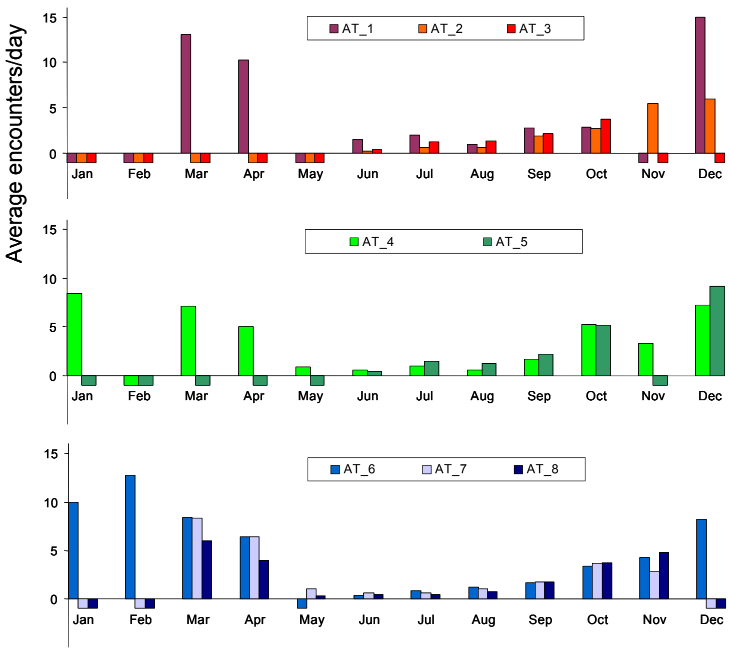


Figure 22. Monthly average of encounters per day for each T-Pod location. Columns below the x-axis indicate when the T-Pod was not functioning.

3.2.4 Baseline data analysis

The change of T-POD at station AT7 did not introduce any significant systematic shift in three of the four indicators (Table 7), although it should be stressed that the test statistic of *POD-id(area station)* for waiting time was close to the significance level. This suggests that the variation attributed to differences in T-POD sensitivity when exchanging T-PODs at a specific location should be taken into account as in the model used. When accounting for the seasonal variation, encounters were an average of 20% longer and waiting times were 43% shorter for T-POD 276 compared to T-POD 231 (the lost T-POD),. Changes in mean daily click intensity and frequency from T-POD231 to T-POD276 were from 25.1 to 24.7 clicks/min and from 0.37% to 0.62%, respectively, although none of these indicators were significant.

Table 7. Analysis of the T-POD specific variation at AT7 (as this position had the only change in T-POD) relative to other sources of variation (Eq. 3) for the four indicators modelled according to Table 4*. The denominator degrees of freedom for the F-statistics were computed by means of Satterthwaites approximation (Littell et al., 1996). The likelihood ratio test was employed for encounter duration.*

Indicator	Factor	Num DF	Den DF	F/χ^2	P
Daily click intensity	*Area*	2	164	2.91	0.0571
	station(area)	5	148	2.54	0.0308
	POD-id(area station)	1	126	0.01	0.9264
	month	11	181	4.79	<0.0001
	area×month	18	175	1.25	0.2302
Daily click frequency	*Area*	2	63.6	2.56	0.0852
	station(area)	5	42.7	1.22	0.3181
	POD-id(area station)	1	42.7	1.40	0.2441
	month	11	120	23.44	<0.0001
	area×month	19	115	0.93	0.5478
Encounter duration	*Area*	2		5.36	0.0684
	station(area)	5		37.10	<0.0001
	POD-id(area station)	1		6.56	0.0104
	month	11		249.67	<0.0001
	area×month	18		39.56	0.0024
Waiting time	*Area*	2	76.7	5.07	0.0085
	station(area)	5	56.6	2.49	0.0417
	POD-id(area station)	1	52	3.34	0.0735
	month	11	125	28.80	<0.0001
	area×month	18	127	1.00	0.4611

A similar seasonal variation for all stations and areas in general were observed for three of the four indicators analysed by Eq. (4) (Table 8). Only the encounter duration modelled by means of the gamma distribution showed significant differences in the seasonal pattern between stations within each area and between the three study areas in general. It should be stressed that the model did not include a specific co-variance structure to take the potential autocorrelation into account. If there is a significant autocorrelation in the encounter observations and it could be included, this would reduce the significance of the factors in the model.

Table 8. Analysis of temporal and spatial variations and their interactions (Eq. 4) for the four indicators modelled according to Table 4. *The denominator degrees of freedom for the F-statistics were computed by means of Satterthwaites approximation (Littell et al., 1996). The likelihood ratio test was employed for encounter duration.*

Indicator	Factor	Num DF	Den DF	F/χ^2	*P*
Daily click intensity	*Area*	2	182	2.82	0.0625
	station(area)	5	197	3.18	0.0087
	month	11	182	4.90	<0.0001
	area×month	18	177	1.34	0.1670
	station(area)×month	29	185	1.32	0.1381
Daily click frequency	*Area*	2	29.6	1.29	0.2909
	station(area)	5	24.8	1.04	0.4165
	month	11	76.1	17.93	<0.0001
	area×month	19	73.7	0.70	0.8023
	station(area)×month	29	69.2	0.43	0.9926
Encounter duration	*Area*	2		4.89	0.0866
	station(area)	5		18.70	0.0022
	month	11		212.63	<0.0001
	area×month	18		49.57	<0.0001
	station(area)×month	29		45.54	0.0261
Waiting time	*Area*	2	56.2	4.49	0.0155
	station(area)	5	53.7	1.90	0.1103
	month	11	104	25.91	<0.0001
	area×month	18	103	0.91	0.5728
	station(area)×month	29	133	0.75	0.8143

The T-POD specific and station-specific seasonal variations could not be estimated simultaneously. Both were significant for encounter duration. The AIC for encounter duration modelled by Eq. (3) was 9301.94 compared to AIC for Eq. (4) of 9318.97 Consequently Eq. (3) was a better model given that it used substantially fewer parameters. This indicated that the significance of *month ×station(area)* in Table 8 could have been caused by the change of T-POD at station AT7. Considering that the model for encounter duration did not include a co-variance structure for autocorrelation between encounters and that both *month ×area* and *month ×station(area)* were not significant for any of the other echolocation indicators, it appeared reasonable to assume a common seasonal variation at all stations (Figure 23).

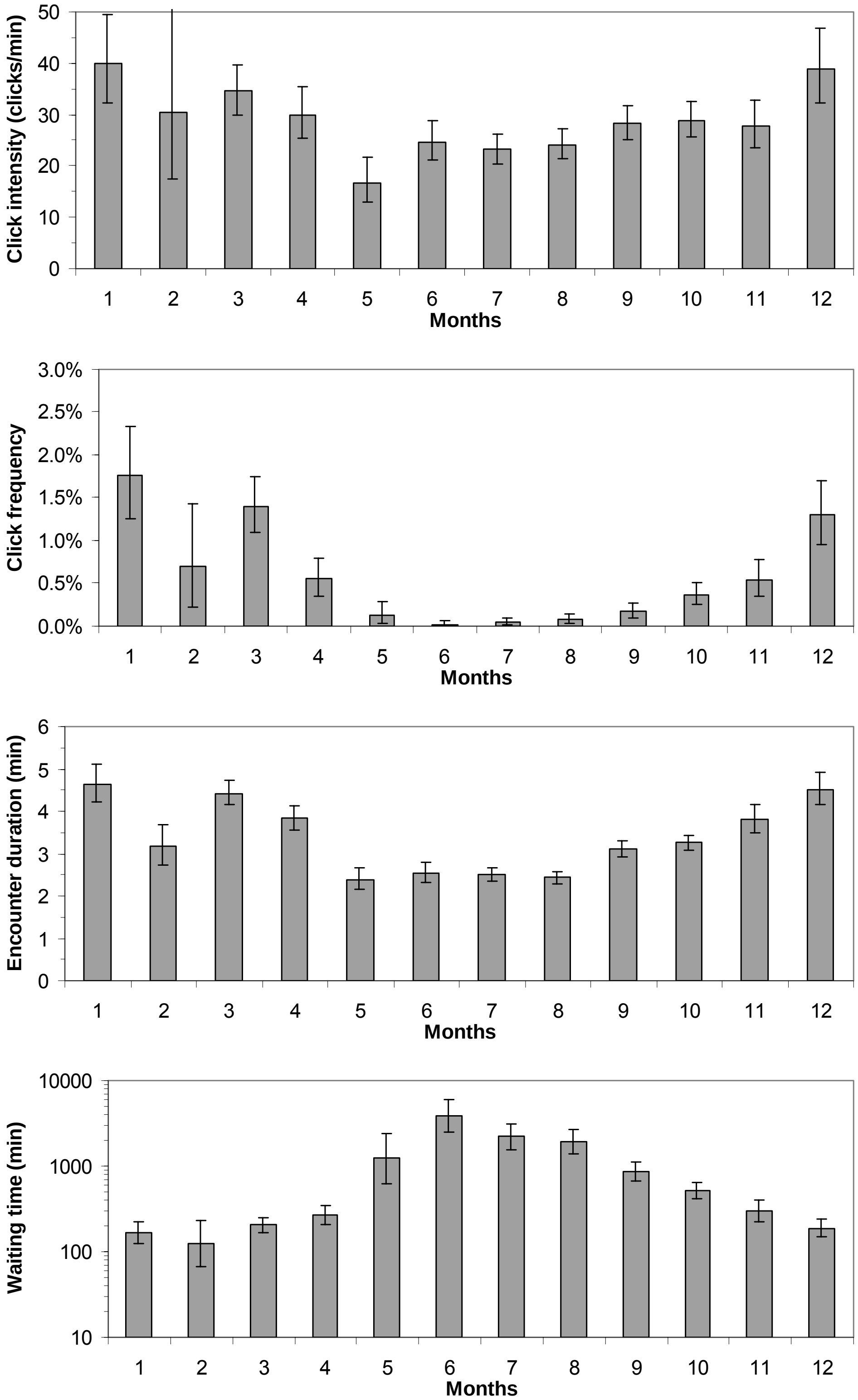


Figure 23. Seasonal means for the four indicators after back-transformation. Error bars indicate 95% confidence limits for the mean values. Variations caused by other significant sources of variation have been accounted for by calculating the marginal means. Note the logarithmic scale for waiting time.

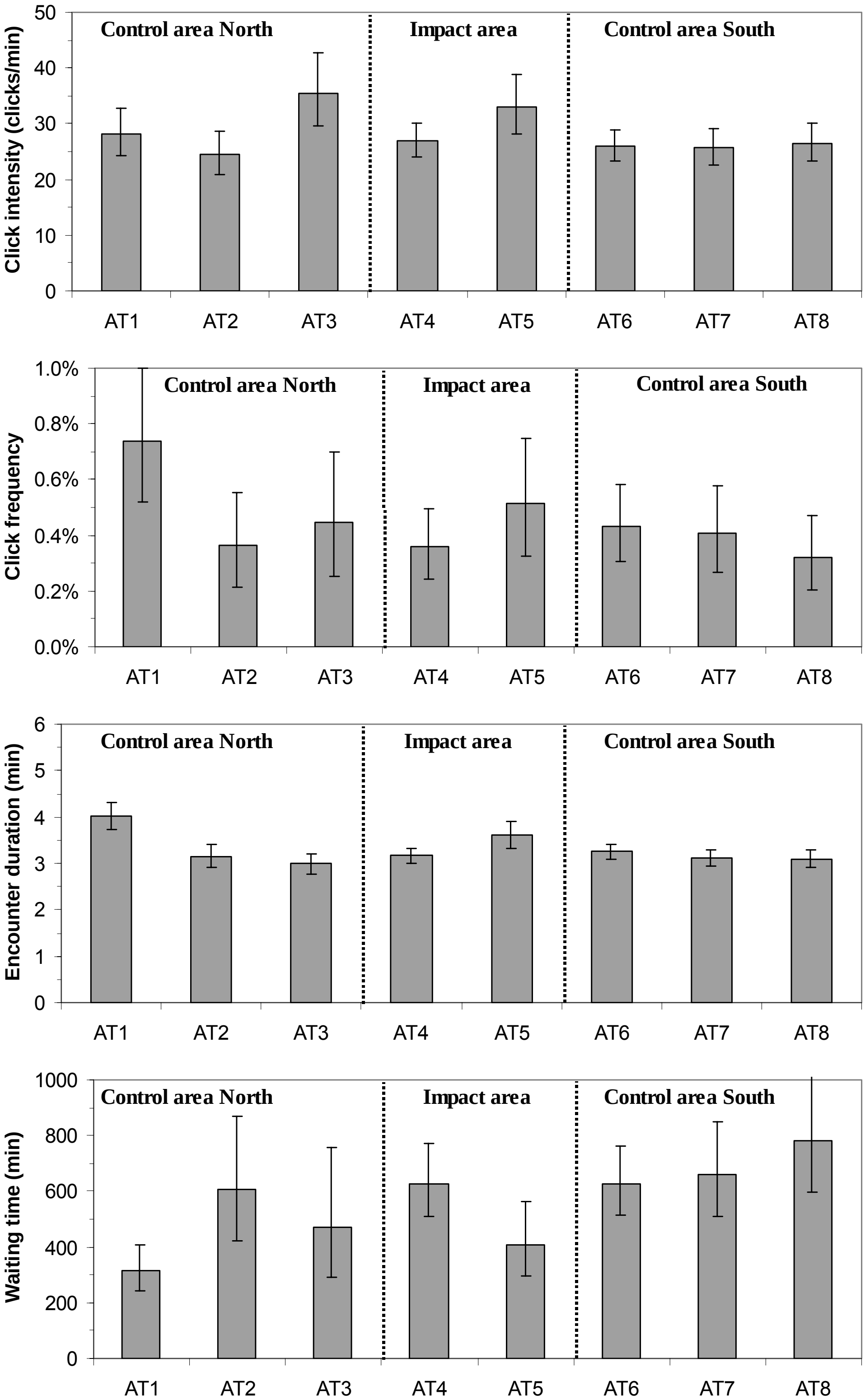


Figure 24. Station-specific means for the four indicators after back-transformation. Error bars indicate 95% confidence limits for the mean values. Variations caused by other significant sources of variation have been accounted for by calculating the marginal means.

Significant spatial variations were found for all indicators except the click frequency where neither *area* nor *station(area)* were significant (Table 8 and Figure 24). Click intensity and encounter duration had significant variations for stations within the three areas, but there was no significant difference in mean levels of the three areas in general. Waiting time, on the other hand, did not reflect significant station-specific variation within the three areas, but there were significant differences between the three areas in general. Spatial variations were substantially smaller than the seasonal variations.

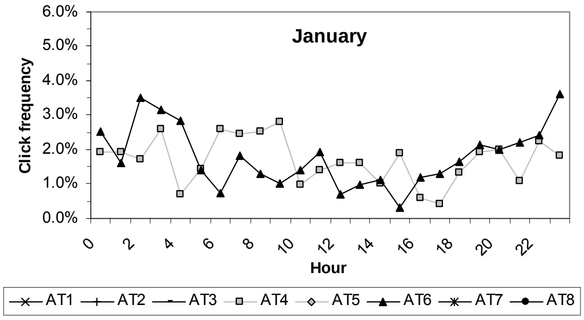
Mean click intensity and frequency at the 8 stations varied from 26 to 36 clicks per minute and from 0.32% to 0.74%, respectively. Encounter mean values at the 8 stations were between 3.0 and 4.0 minutes, whereas the mean waiting time ranged from 5.3 hours to 13 hours. Station AT1 had the highest click frequency and encounter duration and the shortest waiting time, whereas station AT8 had the lowest click frequency and longest waiting time.

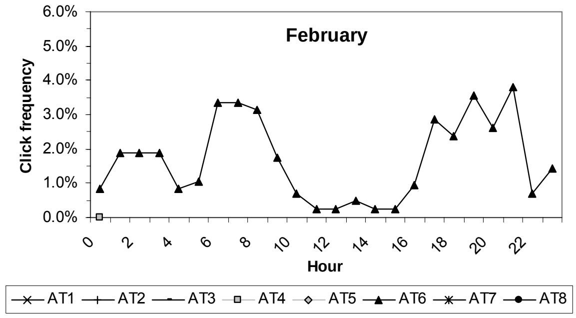
3.2.5 Other sources of variation

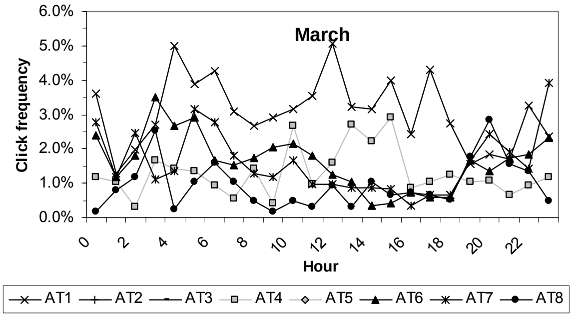
A number of other factors that may influence porpoise echolocation activity were investigated.

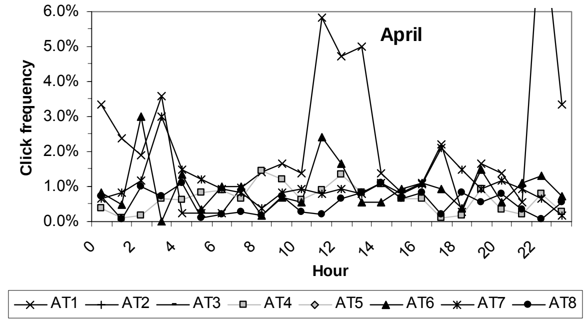
3.2.5.1 Diurnal variation

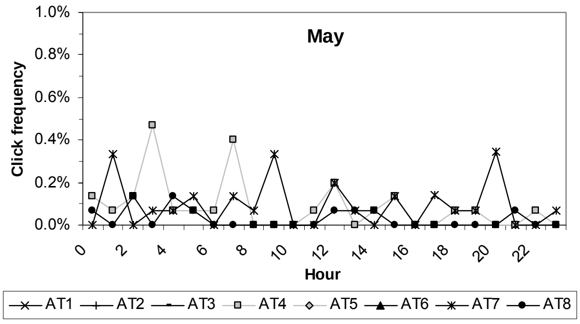
Diurnal variation in echolocation activity could not be assessed by means of the daily indicators (click intensity and frequency) or by waiting time, where observations occasionally spanned over several days. The average click intensity did not show a particular diurnal pattern common to all stations. In the summer months, the number of recorded clicks was low where by, the diurnal pattern was difficult to determine (Figure 25). However in the winter months, from November to February, the click frequency appeared to be lower from 12:00 to 16:00 and higher during the night. This pattern was also reflected at 3 of the 5 stations in March (Figure 25). Thus, there were indications of a diurnal pattern in the echolocation rates, but the indicator models (Eq. (3) and Eq. (4)) were not affected by this, provided that all hours were approximately equally represented in the T-POD data. This assertion appeared valid since the T-PODs were deployed for long periods and logged continuously.

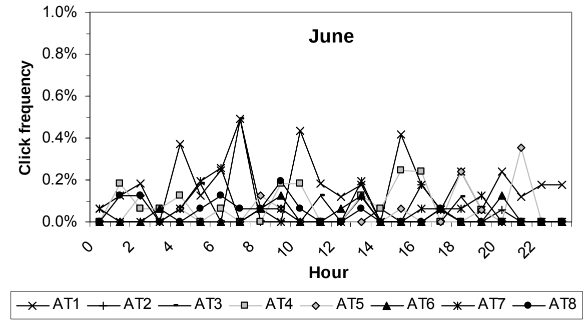

January
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8

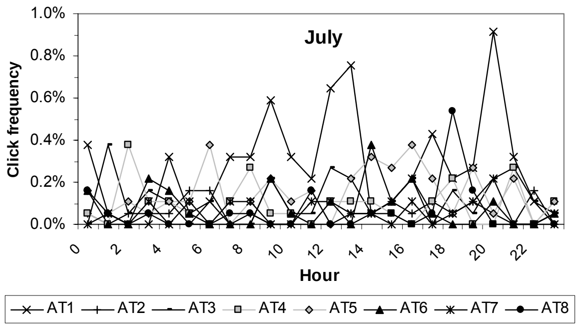

February
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8

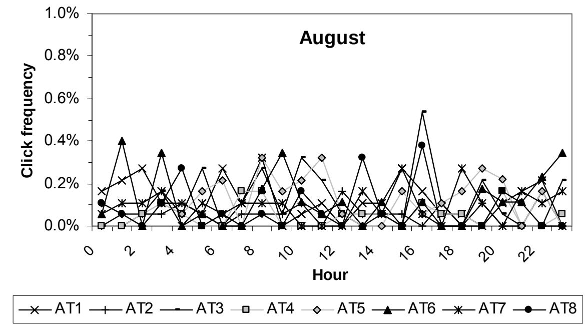

March
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8


April
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8


May
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8


June
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8


July
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8


August
Click frequency
Hour
AT1 AT2 AT3 AT4 AT5 AT6 AT7 AT8

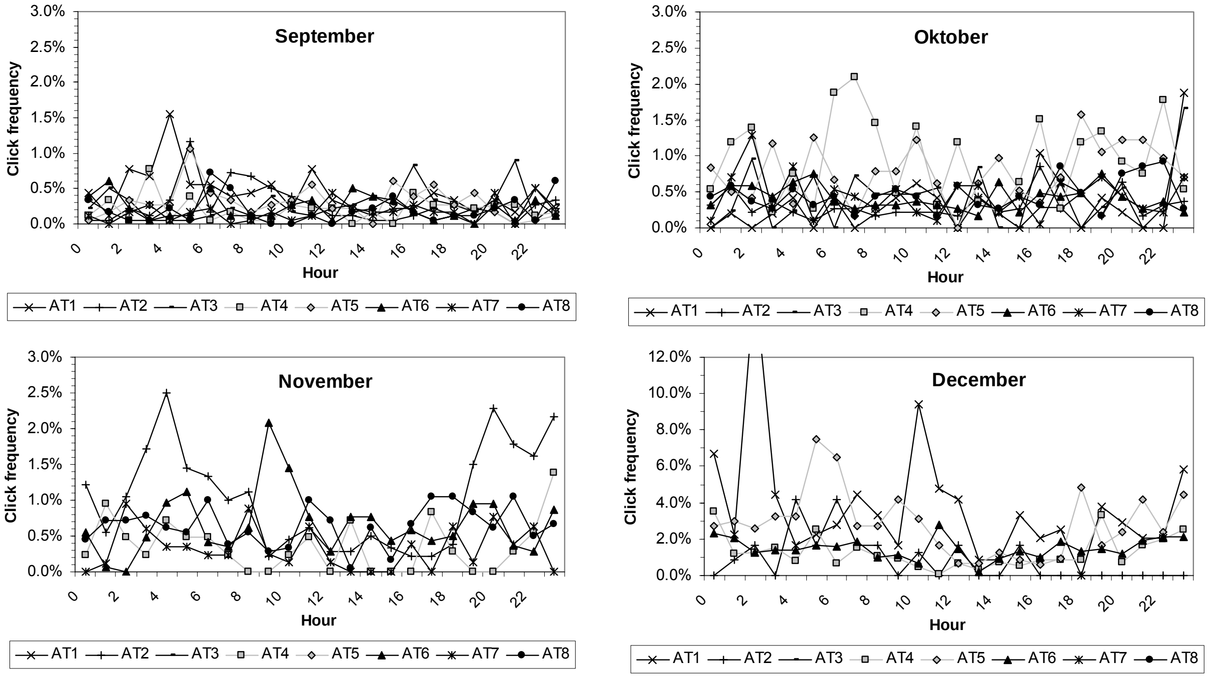
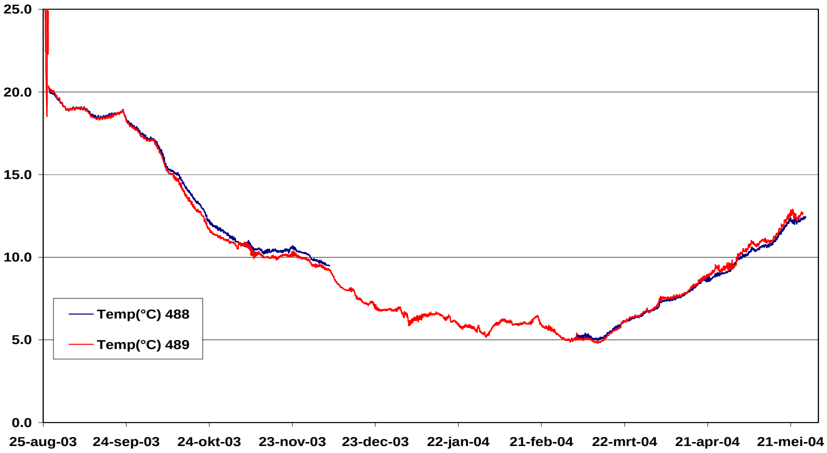


Figure 25. The average click frequency over the day recorded at the 8 stations for all 12 months. Note that the graphs have different scales. Symbols as in Figure 19.

3.2.5.2 CTD field data

The CTDs used proved to work very well. Figure 26 shows the preliminary results. Unfortunately, T-POD AT1 had been lost for some time after December 5th, limiting the amount of data collected by the CTD attached to it. Note that the water temperature in August was extremely high (>20˚C) even at a depth of 20m. It is also interesting to see that sudden changes in salinity occur differently at the two sites; AT5, which is closer to shore, shows more variation and heavier drops in salinity than the most westerly point AT1.



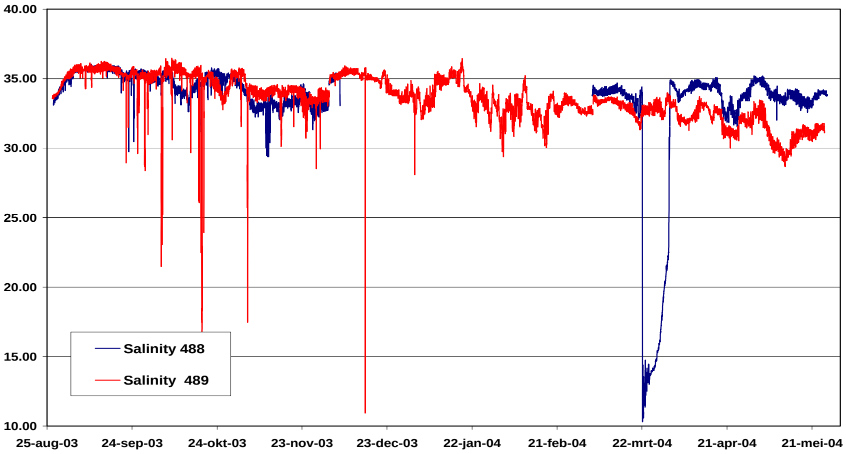
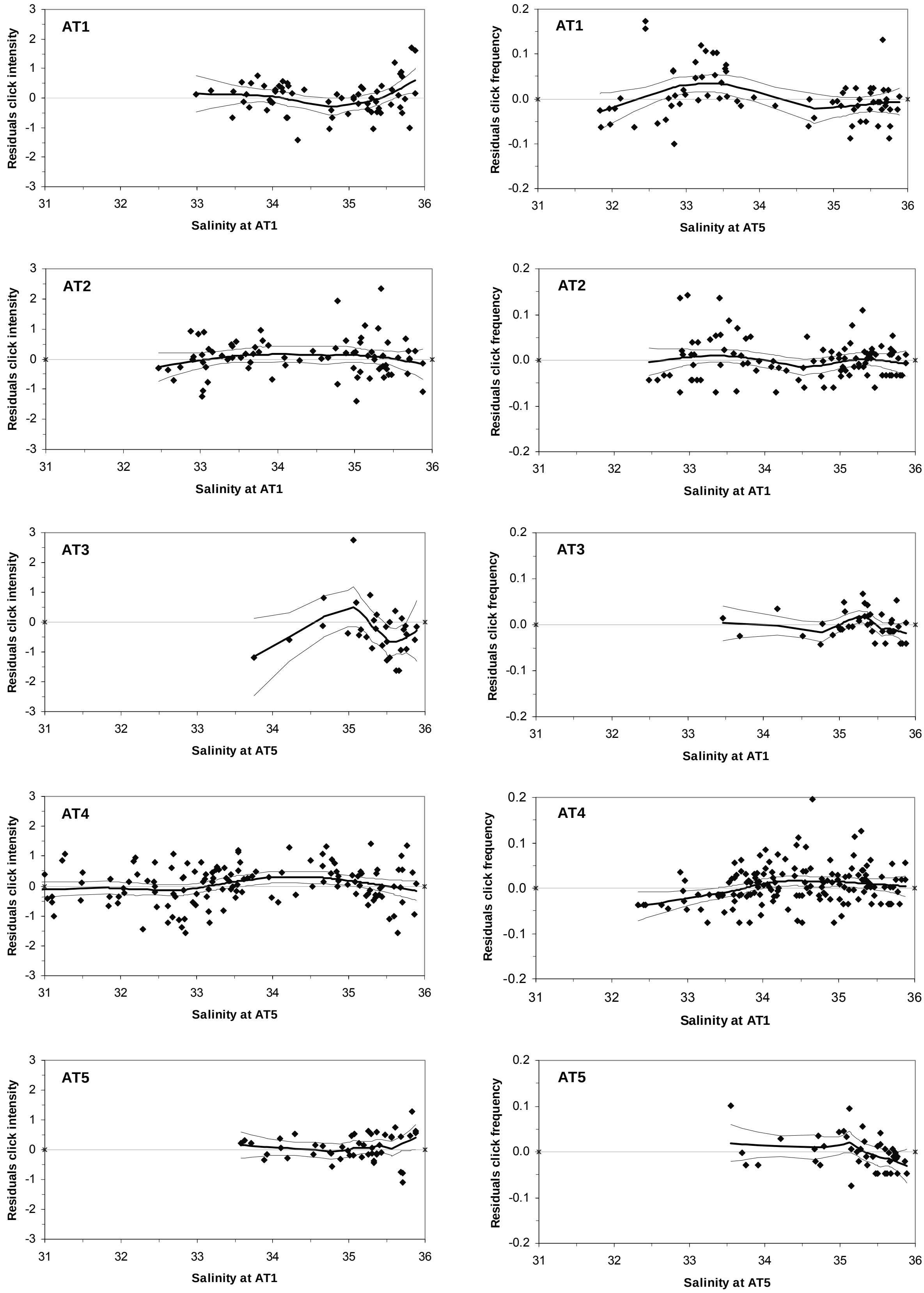


Figure 26. Results of the CTD measurements on location AT1, 488 (20 m depth) and AT5, 489 (18 m depth). Top graph shows the temperature, bottom graph shows the salinity.

3.2.5.3 Correlation with salinity

Although the seasonal, spatial and T-POD specific variation was modelled by Eq. (3), the residuals of click intensity and frequency still contained some systematic behaviour with respect to daily levels of salinity recorded at station AT1 and AT5 (Figure 27). Systematic variations with respect to salinity were also observed for the residuals obtained from modelling encounter duration and waiting time (Figure 28). Although the residuals appeared to deviate systematically from zero at certain salinity intervals at specific stations (e.g. relatively higher click frequency around salinity of 33-33.5 at station AT1), there was no apparent common pattern in these deviations. It should also be acknowledged that the residuals were autocorrelated in time, which may explain these systematic deviations to some extent. Since the residuals were correlated the “true” 95% confidence limits are somewhat higher than calculated under the assumption of independent residuals.


AT1
Residuals click intensity
Salinity at AT1
AT1
Residuals click frequency
Salinity at AT5
AT2
Residuals click intensity
Salinity at AT1
AT2
Residuals click frequency
Salinity at AT1
AT3
Residuals click intensity
Salinity at AT5
AT3
Residuals click frequency
Salinity at AT1
AT4
Residuals click intensity
Salinity at AT5
AT4
Residuals click frequency
Salinity at AT1
AT5
Residuals click intensity
Salinity at AT1
AT5
Residuals click frequency
Salinity at AT5

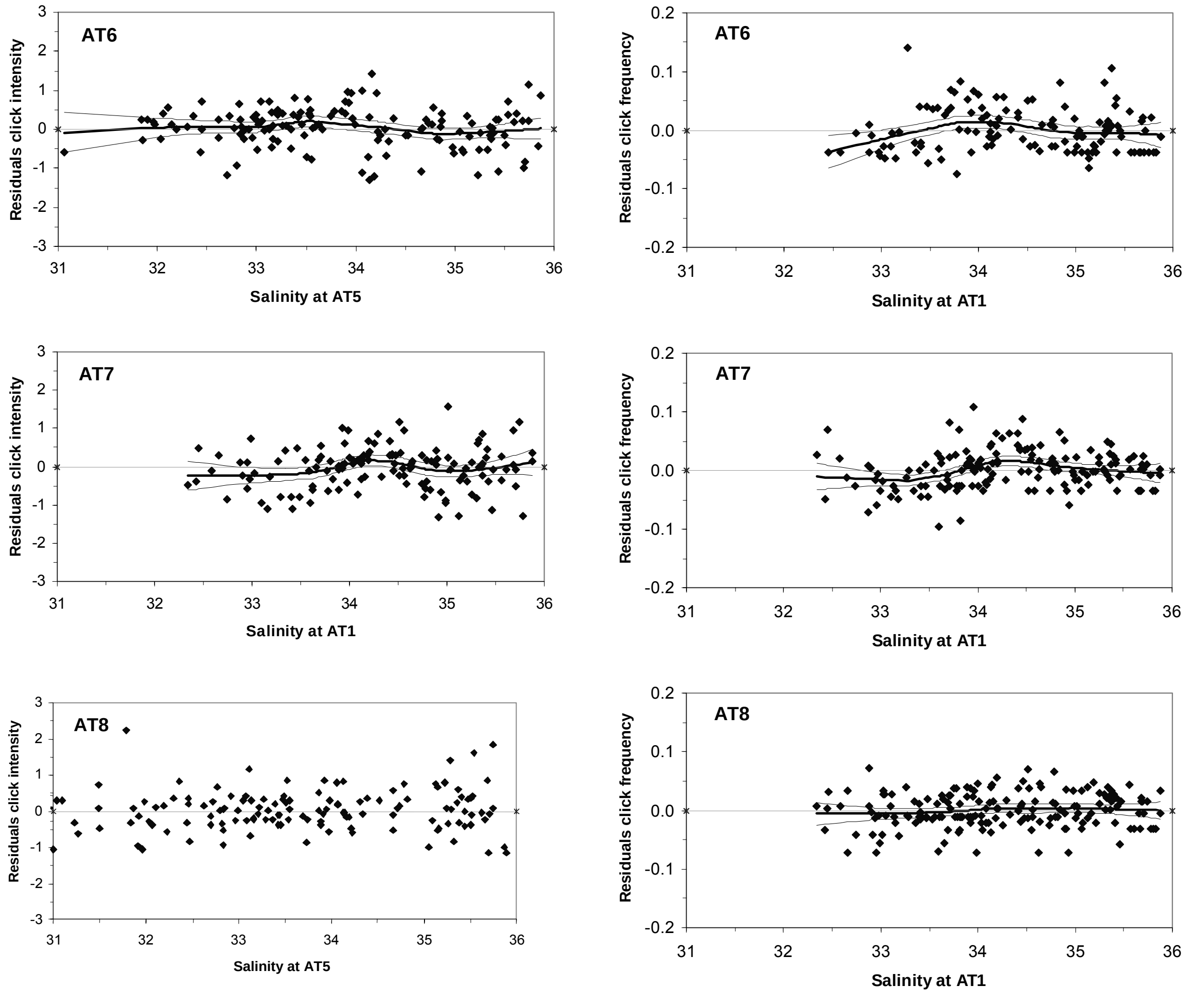
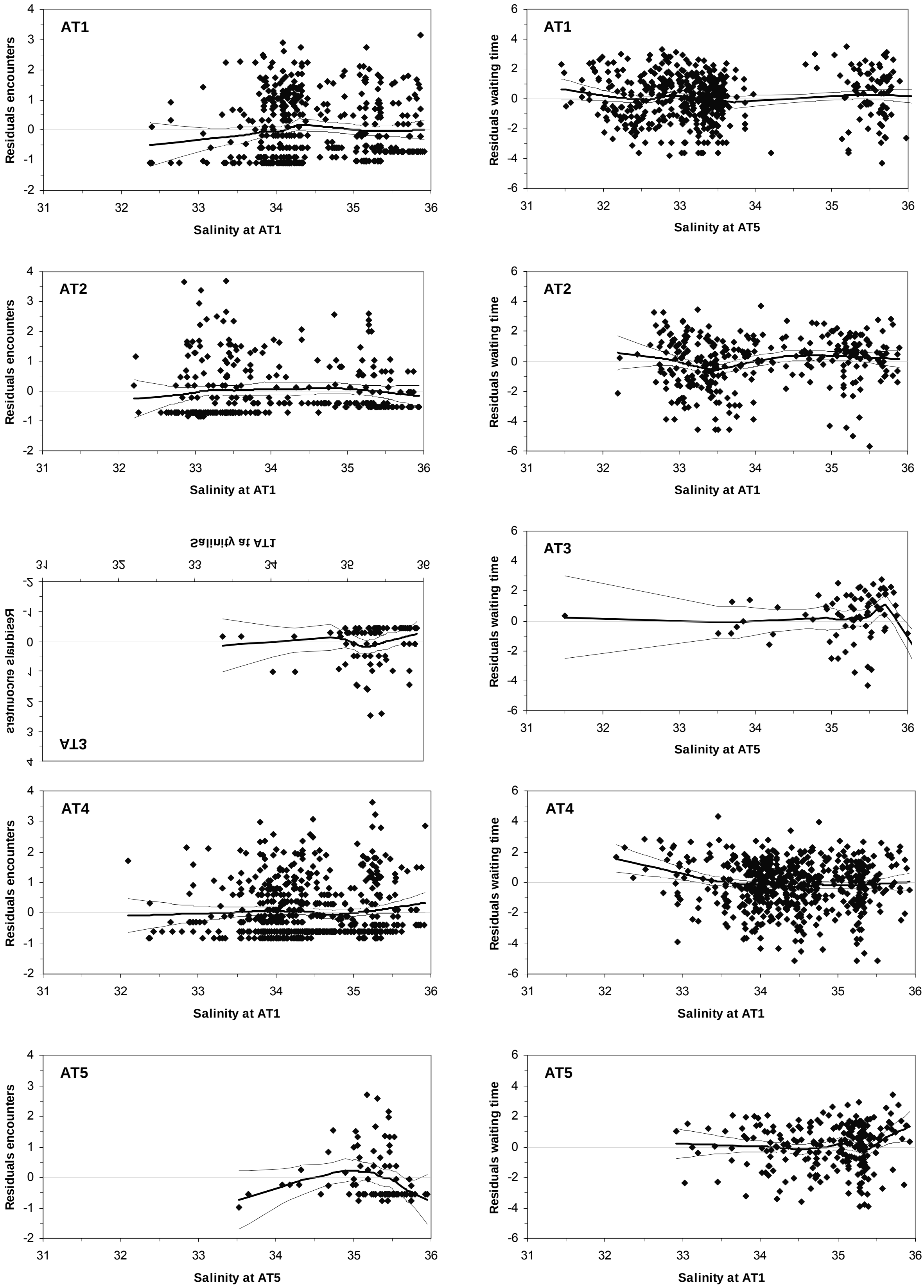


Figure 27. LOESS fit of residuals from modelling click intensity and click frequency according to Eq. (3) versus the corresponding salinity ($^0/_{00}$) measured at station AT1 or AT5. Salinity data are from the station that yielded the lowest residual standard error from the LOESS fit. Thin lines show the 95% confidence limits for the LOESS fit.

The salinity relationship to echolocation activity could be station-specific. Due to loss of T-POD data the salinity ranges were smaller for stations AT3 and AT5, making it more difficult to compare relationships across different stations. However it should be noted that station AT8 showed little residual variation over a wide range of salinity for all four indicators. Moreover, there was no consistent pattern for which salinity data would give the best LOESS fit. Although the two salinity signals showed similar trends, there was no tendency for stronger co-variation in the echolocation indicators to the nearest salinity data.


AT1
Residuals encounters
Salinity at AT1
AT1
Residuals waiting time
Salinity at AT5
AT2
Residuals encounters
Salinity at AT1
AT2
Residuals waiting time
Salinity at AT1
AT3
Residuals encounters
Salinity at AT1
AT3
Residuals waiting time
Salinity at AT5
AT4
Residuals encounters
Salinity at AT1
AT4
Residuals waiting time
Salinity at AT1
AT5
Residuals encounters
Salinity at AT5
AT5
Residuals waiting time
Salinity at AT1

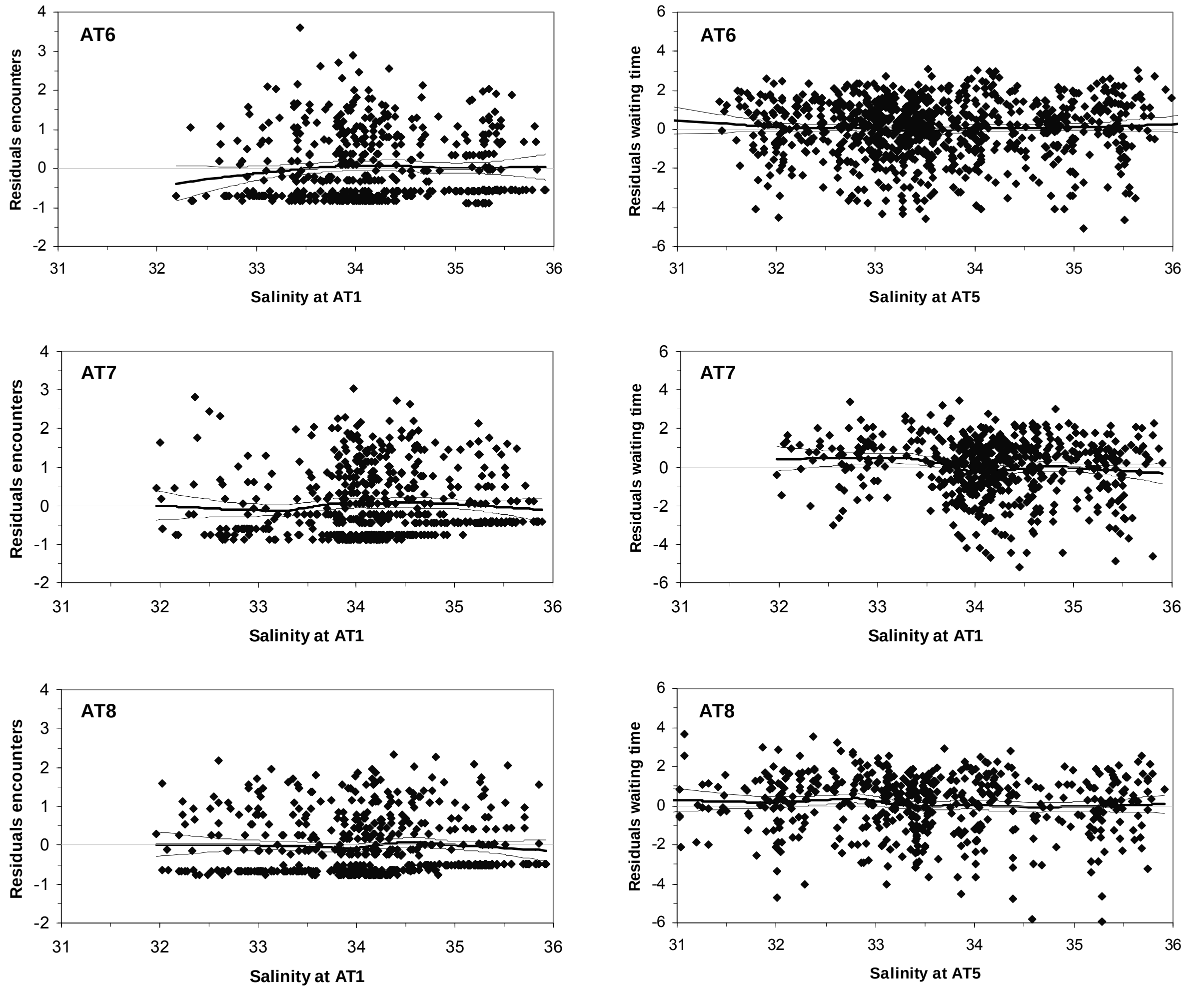


Figure 28. LOESS fit of residuals from modelling encounter duration and waiting time according to Eq. (3) versus the corresponding salinity measured at either station AT1 or AT5. Salinity data are from the station that yielded the lowest residual standard error from the LOESS fit. Thin lines show the 95% confidence limits for the LOESS fit.

3.2.6 Power analysis

In the present baseline study recordings of 1257 click intensities, 1730 click frequencies, 5518 encounter observations and 5500 waiting times were made. The power analysis was carried out using mean values and co-variance structures from these data. Assuming a similar amount of data will be collected during or after construction of the wind farm, the observations used for the simulations were doubled. For the power calculations, we used 2520 and 3600 observations for click intensity and click frequency, respectively. These were derived from 72 different T-POD deployments of approximately 2 months, each consisting of 35 and 50 observations of click intensity and click frequency, respectively. For encounter duration and waiting time, we used 10800 observations derived from 72 (8 T-PODs x 12 deployments over 2 years) different T-POD deployments of 150 observations each.

Given that an equivalent number of observations are collected during or after the wind farm construction, changes of 20% in click intensity, 30% in click frequency, 20% in encounter duration and 50% in waiting time should be detectable with a power >80% (Table 9). Consequently, relatively smaller changes can be observed for click intensity and encounter duration than for click frequency and in particular, waiting time. Click intensity and encounter duration are also related to the behaviour of the harbour porpoises when they are present, which apparently have a less variable data structure than whether the animals are present or not, as given by click frequency and waiting time. The detectable changes with a power above 80% should be compared to variations observed for the four indicators during the baseline study. The ranges in seasonal variation and station-specific variation, assessed as the ratio between maximum and minimum mean values, were 1.39 and 0.46 for click intensity, 81.4 and 2.3 for click frequency, 1.94 and 1.34 for encounter duration and 30.6 and 2.5 for waiting time. Thus, although click intensity and encounter duration had a generally higher power, click frequency and waiting time reflected substantially larger variations.

Consequently, the smaller power for click frequency and waiting time may be compensated for by higher sensitivity in detecting spatial or temporal changes due to the construction and operation of the NSW wind farm.

Table 9. The probabilities of detecting a significant BACI effect given that a relative change in the mean value has occurred in the impact area. The power was calculated as the number of significant tests out of 500 simulations. The values significant at 80% level are highlighted in bold.

Indicator	Relative change				
	10%	20%	30%	40%	50%
Click intensity	24.6	**82.2**	**99.6**	**100**	**100**
Click frequency	14.6	52.6	**84.2**	**98.2**	**99.8**
Encounter duration	77.1	**100**	**100**	**100**	**100**
Waiting time	8.8	22.4	42.8	59.2	**81.6**

3.3 Ship-based surveys

Full modelling of the data was only attempted when there were a minimum of 25 porpoise observations (within 300 m perpendicular distance and within the primary survey area, thus excluding observations made *en route* between the study area and the ship's port) (cf. Pebesma et al., 2000). Only during the February (2004) survey were sufficient numbers of harbour porpoises seen which could be fitted to the model. Numbers of 5-minute counts of porpoise observations within the study area were:

Survey (month, year)	N counts with porpoises
2-2004	93
4-2003	21
5-2003	7
6-2003	0
8-2003	6
9-2002	4
10-2002	5
11-2003	13

In all other months except June, harbour porpoise were found present in the study area, but in densities too low for modelling total numbers. For these months, densities (total numbers) were only estimated from the numbers seen and the total surface areas watched and not by including information on distance from the -20 m line and YFIELD. From the numbers of porpoises seen it is immediately clear that there was a marked seasonal pattern; large numbers of porpoises were present in winter, and lower numbers in the other seasons, particularly mid-summer. This is in line with the T-POD data.

Table 10 gives the total estimated numbers of porpoises, estimated simply from numbers seen and areas surveyed (upper panel) and by full modelling for February when sufficient data could be collected. Note that the estimated numbers have not been subjected to correction factors in this table. Such a correction is applied in Table 11 by multiplying the numbers in Table 10, by a total overall correction factor of 7.66 (see methods section).

Table 10. Results of the ship-based observations. Uncorrected total estimated numbers per survey blocks, based on raw data (measured) above and on Modelled numbers (February only) below.

Measured			totals in sub-area								
month	**NE**	**N**	*NW*	**CE**	**NSW**	**C**	*Q7*	*CW*	**SE**	**S**	*SW*	**Total**
Feb	96 ± 199	43 ± 143	41 ± 169	61 ± 182	6 ± 28	62 ± 199	21 ± 61	12 ± 65	35 ± 125	23 ± 108	20 ± 68	**420**
Apr	4 ± 30	9 ± 77	21 ± 102	2 ± 18	0	2 ± 18	15 ± 59	0	0	12 ± 67	5 ± 49	**70**
May	0	2 ± 26	10 ± 72	0	0	2 ± 19	0	2 ± 14	0	0	4 ± 40	**20**
Jun	0	0	0	0	0	0	0	0	0	0	0	**0**
Aug	0	4 ± 48	4 ± 36	0	8 ± 48	0	0	0	0	4 ± 40	2 ± 18	**22**
Sep	0	4 ± 48	2 ± 23	0	0	0	0	0	2 ± 20	0	2 ± 19	**10**
Oct	0	10 ± 81	0	4 ± 27	0	3 ± 25	0	0	0	10 ± 55	0	**27**
Nov	3 ± 20	24 ± 120	11 ± 55	4 ± 38	0	5 ± 42	6 ± 33	0	9 ± 50	0	0	**62**

Modelled			totals in sub-area								
month	**NE**	**N**	*NW*	**CE**	**NSW**	**C**	*Q7*	*CW*	**SE**	**S**	*SW*	**Total**
Feb	**63 ± 9**	**81 ± 14**	**46 ± 8**	**69 ± 9**	**19 ± 1**	**36 ± 4**	**13 ± 1**	**13 ± 1**	**47 ± 7**	**32 ± 6**	**18 ± 3**	**437**

Table 11. Total numbers estimated to have been present per sub-area and month, after full correction for animals missed by the observers (including corrections for observer, perpendicular distance and g(0): see text.

Measured			totals in sub-area								
month	**NE**	**N**	*NW*	**CE**	**NSW**	**C**	*Q7*	*CW*	**SE**	**S**	*SW*	**Total:**
Feb	736	330	314	468	46	476	161	92	268	176	153	**3220**
Apr	31	69	161	15	0	15	115	0	0	92	38	**536**
May	0	15	77	0	0	15	0	15	0	0	31	**153**
Jun	0	0	0	0	0	0	0	0	0	0	0	**0**
Aug	0	31	31	0	61	0	0	0	0	31	15	**169**
Sep	0	31	15	0	0	0	0	0	15	0	15	**76**
Oct	0	77	0	31	0	23	0	0	0	77	0	**208**
Nov	23	184	84	31	0	38	46	0	69	0	0	**475**
Modelled			totals in sub-area								
month	NE	N	NW	CE	NSW	C	Q7	CW	SE	S	SW	**Total:**
Feb	483	621	353	529	146	276	100	100	360	245	138	**3351**

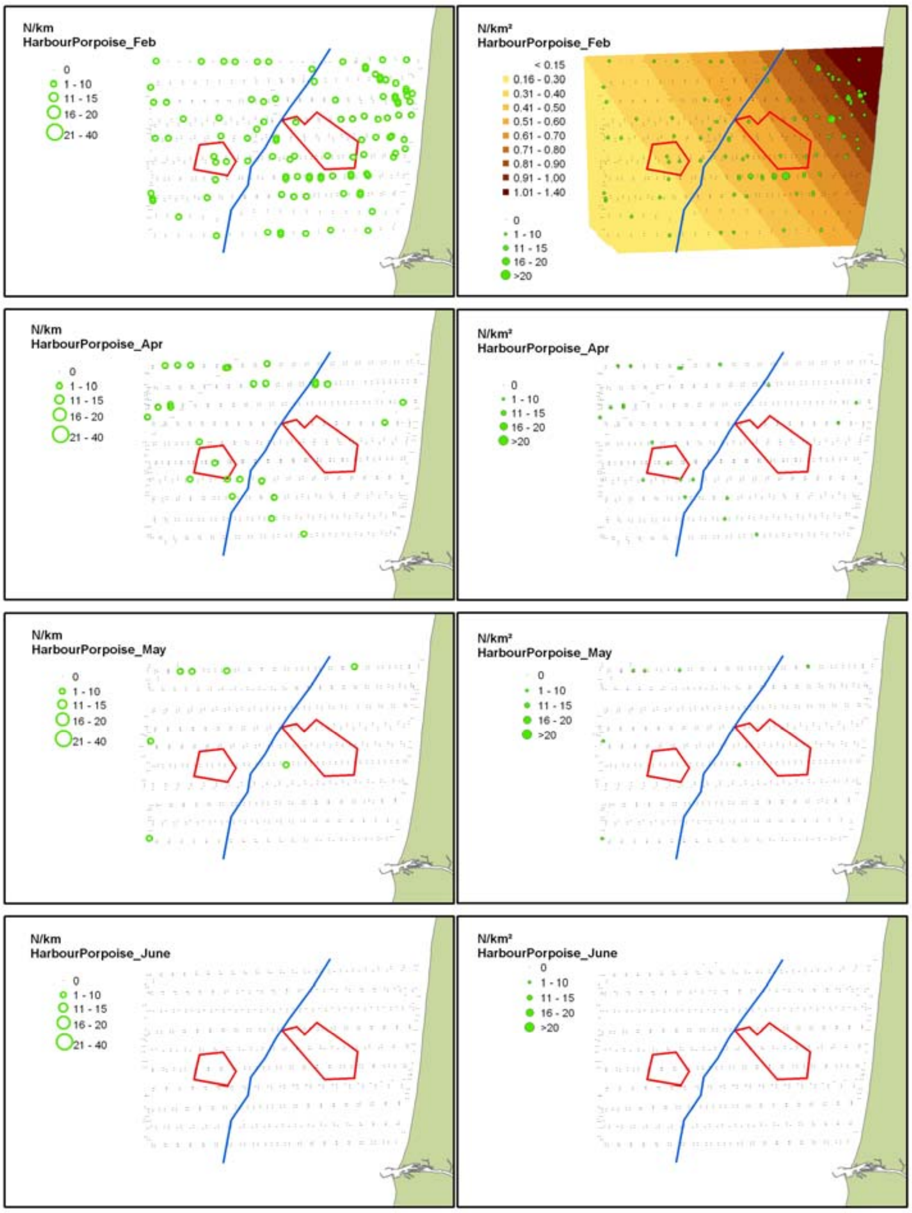


Figure 29. Distribution (expressed as numbers seen per km sailed, left) and density (numbers per km², right) of Harbour Porpoises per survey. For the distribution maps all sightings were used; for the density maps only the sightings made within 300 m perpendicular distance. Model results are superimposed on the density map of the February survey: a full model could only be made for the February data.

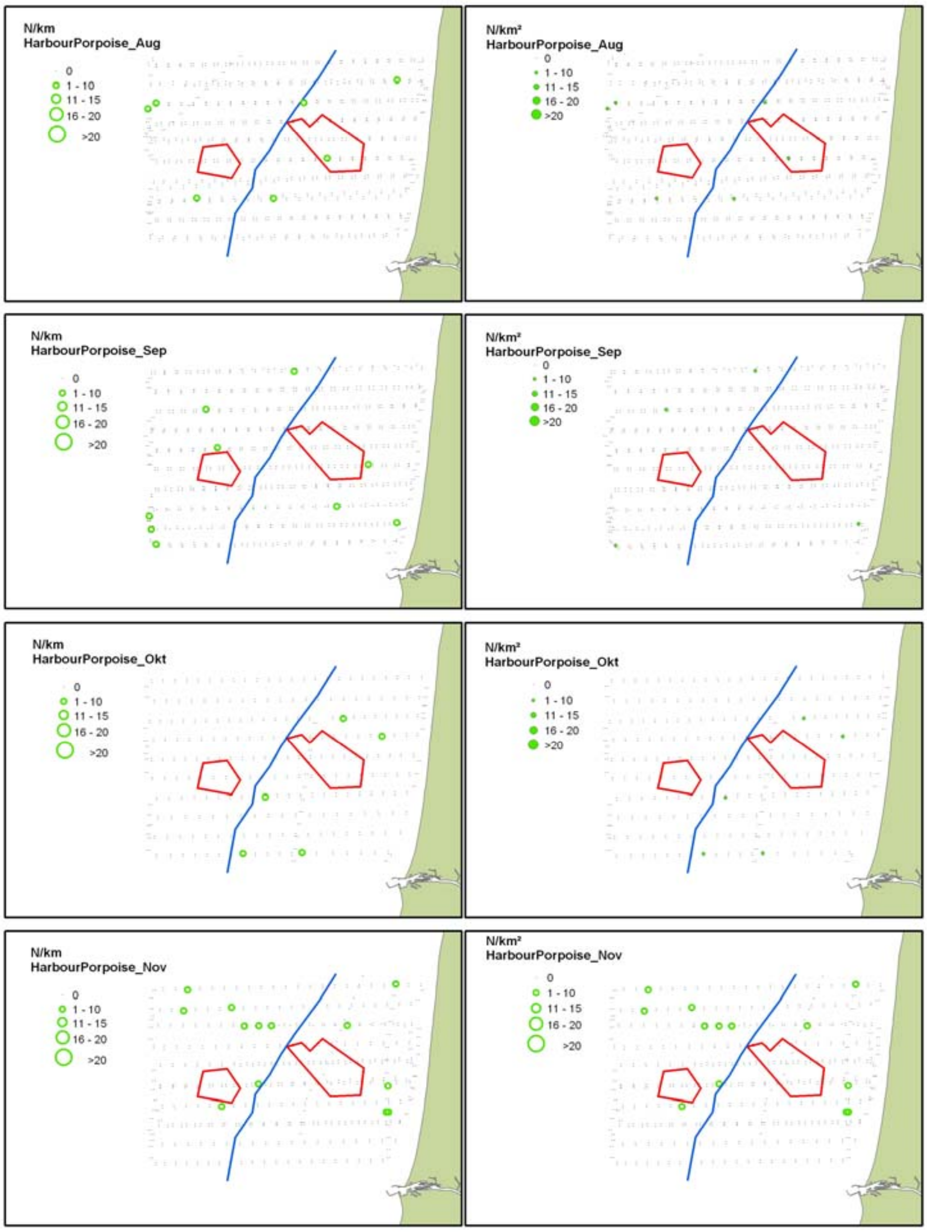


Figure 29 –continued-. Distribution (numbers seen per km sailed, left) and density (numbers per km², right) of Harbour Porpoises per survey.

3.3.1 Towed Hydrophone

The initial intention was to use passive acoustic monitoring on three surveys. Data were successfully collected during the August survey (11 – 15 August 2003), but porpoise densities were low, making a comparison between acoustic and visual data difficult. The towed acoustic component on the second survey was cancelled as a cost-cutting measure. On the final survey the Computerboard card malfunctioned which also caused the computer to permanently stop working. Replacement equipment did not reach the field team in time. The cause of this problem in a part of the system which is well tested and commercially available are being investigated with the manufacturer.

The passive acoustic equipment was installed on the bridge and no problems were encountered with electrical noise. It was evident from the detection files that the vessel itself was noisy but useful data could still be collected. Noise levels were significantly lower at night, when vessel speed dropped to ~5 knots than during the day when a speed of~10 knots was maintained. Figure 30 shows the noise level decreasing as the vessel slowed down at the end of the sighting day.

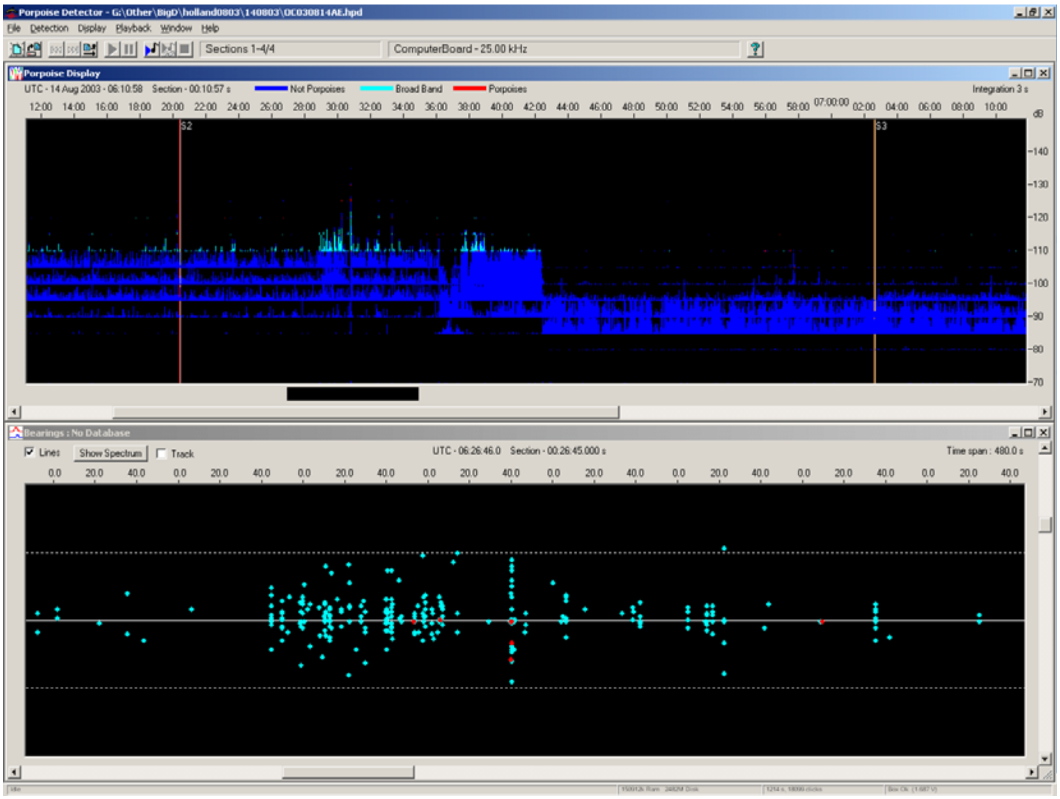


Figure 30. Note decrease in noise level when vessel speed decreased from ~10 to ~5 knots.

Immediately after the survey, the acoustical data were reviewed and the certain detections were extracted from the data files. Twelve such porpoise detection events were found (e.g Figure 31) and four possible porpoise events. Rates of detection were higher at night probably because vessel speed and hence, vessel noise were lower. The visual and acoustic detection rates during the day were similar but were poorly correlated (Figure 32). That is, detections that were made acoustically were often not seen and visual detections were often not heard. This indicates that both detection methods, visual and acoustic, were probably missing a substantial proportion of the animals within range (conform the substantial correction factors calculated for the visual survey data). There are two likely explanations for missed acoustic detections and both are related to boat noise. The first is simply that high levels of background noise mask or interfere with the detection of porpoise clicks. The second is that noisy boats cause animals to move away and avoid the vessel. The field operator remarked that most porpoises she observed were heading away from the vessel and this seemed more marked than she had observed on other porpoise surveys (further examination of the visual data may help to confirm this).

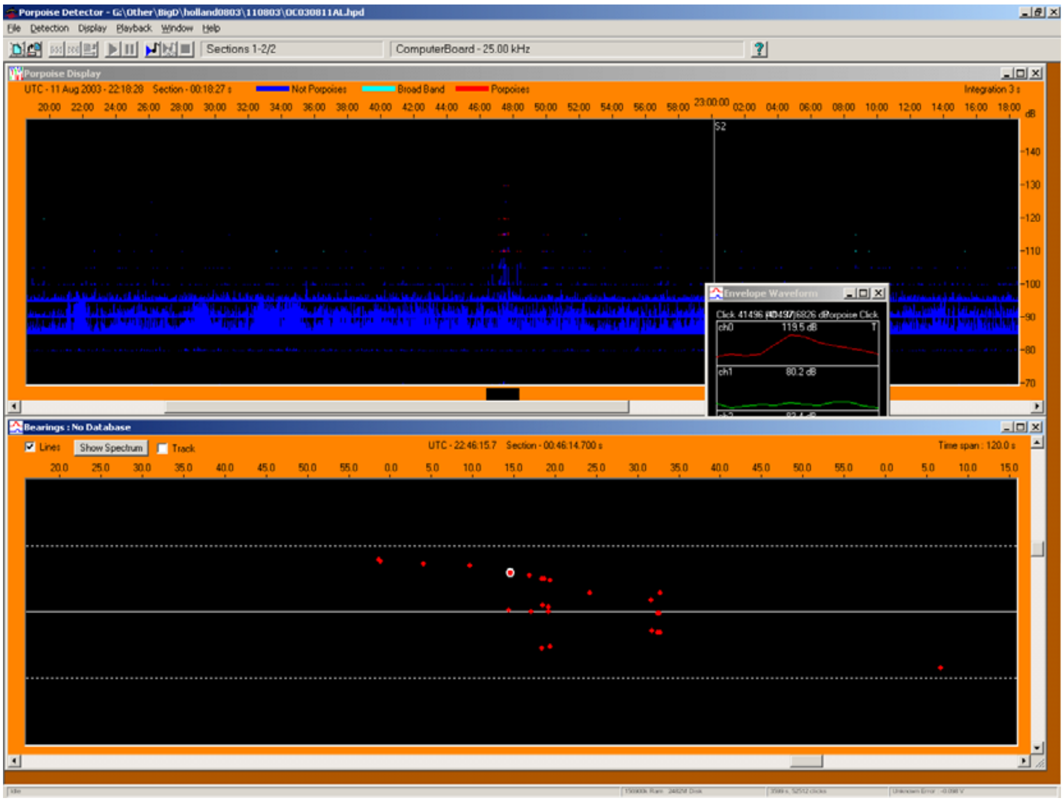


Figure 31. An example of an obvious porpoise acoustic detection event during the current survey

Porpoises presumably respond to the noise generated by the ship and one might expect this effect to be worse for noisier vessels. Of course this is a problem for both visual and acoustic surveys (and it emphasises the importance of considering UW noise generation when choosing a vessel for cetacean surveys), but we must expect it to have a rather more severe effect on acoustic detection rates for two reasons. In the first case, porpoise vocalisations are directional, so that the detection rates of porpoises may fail if oriented away from a hydrophone. Secondly the hydrophone is towed 100m astern of the vessel. By the time it comes abeam of a pod, the porpoises will have been exposed to the highest levels of boat noise and be more likely to have re-oriented or moved away. This emphasizes conflicting requirements in the characteristics of vessels for these two types of survey. Small, quiet and often inexpensive vessels are ideal for acoustic surveys but usually do not provide good visual platforms while the larger vessels typically used in visual surveys are often too noisy to be ideal acoustic survey vessels. However even given these constraints, passive acoustic monitoring can be a useful addition to a visual survey. Potentially it can provide independent detection data to calibrate sighting rates and it allows surveys to continue (often at a slower speed) during periods of darkness and poor sighting conditions.

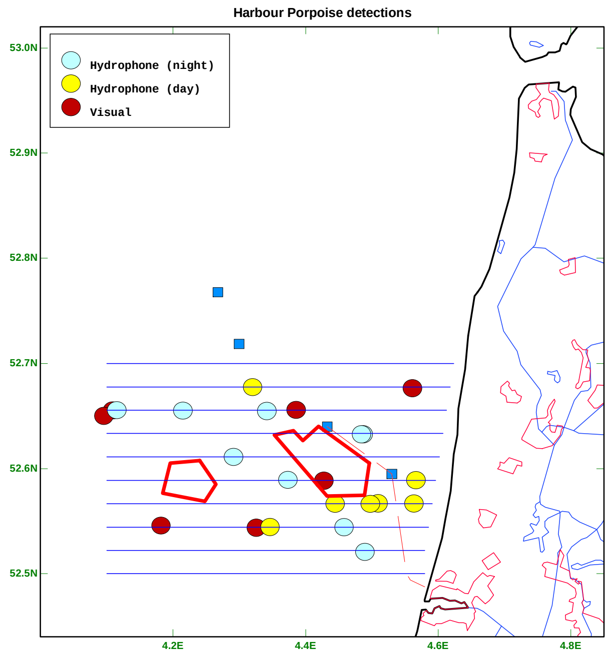


Figure 32. Harbour Porpoise sightings and hydrophone detections, 11-15 August 2003.

4 Conclusion

4.1 Conclusion of the results

This study documents the status of the harbour porpoise in a localised coastal area west of the Dutch province of North-Holland. The frequency of porpoise recordings in this area exceeded our expectations based on existing data for the area. The results fit well in a long-term trend found by the coastal seawatching programme of the Dutch Seabird Group (1972-2004 data; Camphuysen unpubl. material).
Three methods were used to study the occurrence of harbour porpoises in the study area: stationary passive acoustic monitoring (T-PODs), ship-based visual surveys and a concurrent hydrophone survey.

The hydrophone survey was only planned on three occasions, one of which was cancelled due to bad weather and another was unsuccessful due to technical errors. As a result, the towed hydrophone technique did not produce much data. It is difficult to draw conclusions based on this technique, other than the fact that visual observations do not necessarily coincide with the acoustic observations. Technical improvements are underway which may make this technique more robust in the future. Ameliorated hydrophone techniques may enable us to be less dependant on the weather to collect data on the distribution and abundance of the porpoise, especially in areas with lower densities or at night.

Visual surveys are most reliable in fine weather conditions (sea state 3 or less); such conditions are relatively rare at sea. Nevertheless, the ship-based surveys have proved valuable in estimating porpoise density. Maximum numbers in February were estimated at 420 individuals (uncorrected) and 3220 individuals (corrected) in the study area at large, and at 46 (146 corrected) animals within the NSW area (Table 11). Modelled data for February show a slight gradient in density from southwest, where numbers are relatively low, to slightly higher numbers in the northeast. The surveys also show a strong seasonal pattern, with winter surveys producing many more sightings than summer surveys. Not a single harbour porpoise was observed in June.

Acoustic observations with T-PODs were collected at eight locations using T-PODs. The T-PODs were operated continuously during one year, although during the study some T-PODs were lost (and later recovered) and there were a few cases where technical flaws or limited memory capacity resulted in less data than was foreseen.

In the field calibration, it was demonstrated that the individual T-PODs collected very similar harbour porpoise recordings, with the exception of one T-POD which showed lower sensitivity and therefore fewer echolocation recordings. This difference in sensitivity was accounted for in the data analysis.

As in the surveys, T-PODs show a strong seasonal pattern in porpoise echolocation activity, with significantly more records in autumn, winter and spring than during the summer months (Figure 33). A significant effect of month is observed in the four indicators that were chosen for the analysis; click intensity, click frequency, encounter duration and waiting time.

Though substantially less pronounced than the temporal variations, the indicators (except for click intensity) also show significant spatial variations (between T-PODs. However, in general the three areas chosen (study site and two control sites) were not significantly different, though the northern site (T-PODs AT1- AT3) does show slightly higher activity.

Diurnal variation in echolocation activity was only observed in winter months. The click frequency appeared to be lower between noon and 4 pm and higher during the night. Activity was more evenly distributed in summer.

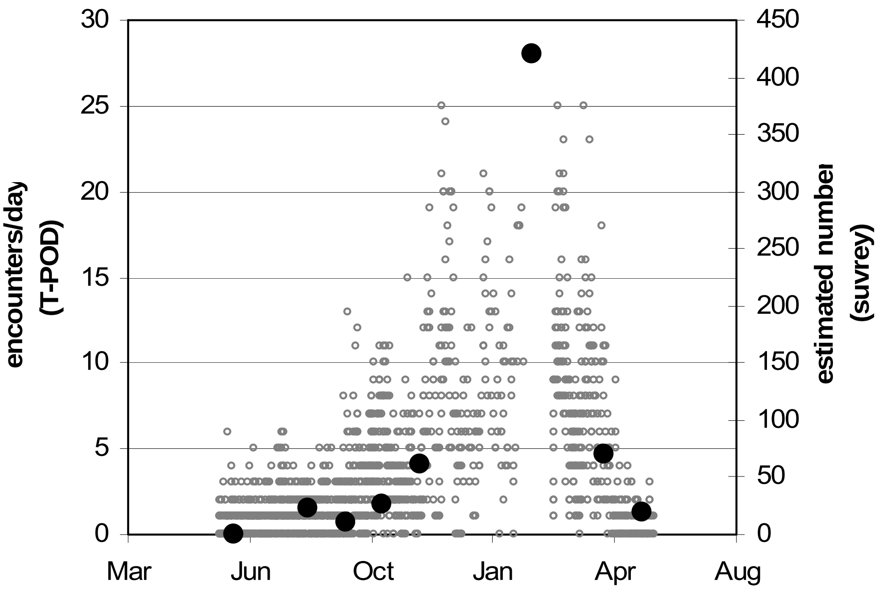


Figure 33. Comparison of the encounter rate provided by the 8 T-PODS (grey circles) and the number of porpoises in the study area provided by the ship-based surveys (black dots)

T-PODs proved to be a powerful method to collect data on presence and seasonal distribution of harbour porpoises in NSW. Data collected during the baseline period was shown to be sufficient to detect changes (at 80% level) in porpoise echolocation behaviour at the 20% level for the indicators click intensity and encounter duration, 30% for click frequency and 50% for waiting time.

The amount of data collected by the T-PODs in this study and the levels of significance in the power analysis is similar to other studies that have demonstrated significant effects of wind farm construction on harbour porpoises in Denmark (Carstensen et al. submitted). We are therefore confident that the T-POD data collected during the baseline study constitute a good basis for determining potential effects on harbour porpoises from the construction and operation of the planned wind farm (NSW).

Extensive quantitative comparison of the T-PODs and more widespread observation methods (ship-based observations) is beyond the scope of this study. It is important to stress that monitoring programs using T-PODs and survey programs supplement each other well, with almost no redundancy. Surveys have high spatial resolution, but a temporal resolution that is dependant on the intensity of surveying, i.e. data was collected in this study in six periods within a year. The situation is exactly the opposite for T-PODs (very high temporal resolution but a spatial resolution that is dependant on the density of the T-PODs used. In this study 8 PODs were placed within 200km^2). Figure 33 shows that the trend in the porpoise presence in the area coincides strongly with the T-POD data.

4.2 Recommendations for set up in T_1

The combination of the T-PODs and visual surveys proved to be adequate to provide high quality baseline data. Continuation would therefore be advisable in the T_1. However both surveys and T-PODs could be ameliorated to provide for even more extensive data and enable quantitative comparison.

Ship-based surveys could be improved by including more dedicated porpoise work (protocol adjustments, dedicated observer). Most importantly, it should be attempted to estimate g(0) directly during the survey, either by using double platform techniques (*sensu* SCANS) or by incorporating good and matching data from a simultaneously operated hydrophone and preferably both.

The large amount of data collected by the T-PODs guarantees the power of the analysis when examining possible changes in echolocation activity due to construction and operation of wind farms. To optimize the data collection a number of technical ameliorations could be enforced in the setup of the T_1. Considering the fact that five of the eight T-PODs were detached from their anchoring at some point in time, despite the relatively heavy equipment, improvement could include a better mooring technique, maybe protecting the T-POD from trawls under water. Some data was also lost in winter when the memory became full due to high porpoise activity and maybe other sounds like caused by wind and waves. Newer versions of the T-POD have more memory capacity. In addition a higher servicing intensity in winter could also prevent the problems mentioned above. Finally, though not imperative to measure windmill effects, the interpretation of the recorded clicks would be facilitated, if there were more knowledge on the circumstances under which the porpoises produce clicks.

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Appendix 1 Technical Specifications Star –Oddi DST-CTD

Size (diameter x length)	15 mm x 46 mm
Weight (in air/in water)	19g / 12g
Memory capacity	DST CTD 43582 measurements pr. sensor
Memory type	Non-volatile EEPROM
Conductivity range	3 mS/cm to 69 mS/cm**
Salinity range	4 - 38 PSU**
Temperature range	-1°C to +35°C (30°F to 95°F)**
Depth range	0.5 to 700 m**
Resolution temperature	0.032°C (0.058°F)
Resolution depth	0.03% of full scale (FS)
Resolution salinity	0.05 PSU
Accuracy temperature	+/-0.1°C (0.18°F)
Accuracy depth	+/-0.4% of selected range
Accuracy salinity	better than +/-0.5 PSU
Accuracy conductivity	+/-0.4 mS/cm
Clock	Real time clock. Accuracy +/-1 min/month
Sampling interval	From 1 second and up to 90 hours
First recording	At once or at any future time
Computer interface	RS-232C, 9 pin
Battery life	3 years***
Data retention	25 years
Attachment hole	0.9 mm (in diameter)

Calibration refs CTD S0488(*.RIT);

Recorder type : DST CTD
Recorder number : S0488
Recorder version : 6
Recorder measures : Temperature, Pressure & Conductivity
Memory capacity : 43581
Production number : 82350488
Production date [dd:mm:yy] : 23:05:03

Calibration number : 1
Calibration date[dd:mm:yy] : 23:05:03
Calibration constants:
Temp.C0: 138.509196314586
Temp.C1: -0.18407681148486
Temp.C2: 0.000157449533097304
Temp.C3: -8.19348644463913E-8
Temp.C4: 2.21256555783699E-11
Temp.C5: -2.49785283246788E-15

Pres.C0: -1.15524755481282
Pres.C1: 0.0044167358151741
Pres.C2: -3.24705710106815E-7
Pres.C3: 2.27390116548498E-10
Pres.C4: -7.03283276585787E-14
Pres.C5: 7.94355828576273E-18

TPR.C1 : -4.97763047866069
TPR.C2 : 0.0988481651464802
TPR.C3 : -0.001704720196216
TPR.C4 : 9.41504089368584E-6
TPR.C5 : 5.01189851896302E-8

Ambient pressure (mbar) : 1012
Temperature reference (°C): 22.70

Conduc.C0: 88.5703167808827
Conduc.C1: -0.162251993764651
Conduc.C2: 0.000146547725205369
Conduc.C3: -6.68928364146958E-8
Conduc.C4: 1.46888335485746E-11
Conduc.C5: -1.23117632630623E-15

TCR.C1 : 0.545641161627429
TCR.C2 : -0.187219063823518
TCR.C3 : 0.0046140896778426
TCR.C4 : 1.06977535361448E-5
TCR.C5 : -9.96254983704496E-7

Temperature reference (°C): 24.13

calibration refs CTD S0489(*.RIT);

Recorder type : DST CTD
Recorder number : S0489
Recorder version : 6
Recorder measures : Temperature, Pressure & Conductivity
Memory capacity : 43581
Production number : 82350489
Production date [dd:mm:yy] : 23:05:03

Calibration number : 1
Calibration date[dd:mm:yy] : 23:05:03

Calibration constants:
Temp.C0: 138.844068158333
Temp.C1: -0.185093980943255
Temp.C2: 0.000158450899881603
Temp.C3: -8.23756646912598E-8
Temp.C4: 2.22113537857503E-11
Temp.C5: -2.50190328765713E-15

Pres.C0: -1.69009480300193
Pres.C1: 0.00435791919201861
Pres.C2: -9.65279365777692E-8
Pres.C3: 8.27218214656036E-11
Pres.C4: -2.01505189097998E-14
Pres.C5: 1.10364494802304E-18

TPR.C1 : -0.944241239808807
TPR.C2 : 0.0186802847840338
TPR.C3 : -0.00191628236212751
TPR.C4 : 5.6475254711205E-5
TPR.C5 : -5.18090492475405E-7

Ambient pressure (mbar) : 1012
Temperature reference (°C): 22.69

Conduc.C0: 90.5574802638884
Conduc.C1: -0.167222371558879
Conduc.C2: 0.000152227525070555
Conduc.C3: -7.03355354986885E-8
Conduc.C4: 1.56863013745128E-11
Conduc.C5: -1.33838077385758E-15

TCR.C1 : -1.99031012020113
TCR.C2 : 0.0772935292177754
TCR.C3 : -0.00999622181937846
TCR.C4 : 0.000342416919592604
TCR.C5 : -3.61711719431617E-6

Temperature reference (°C): 24.13

Appendix 2 Overview of the status of the T-PODs during the measurements

Position name	T-POD	depth (m)	3-4/06/03	26/08 /03	11/10/03	20/11/03	02/12/03	10/12 /03	08/01/04	17/02/04	04/03/04	25-26/05/04
AT 1 (CTD 488)	238	20	Deployed	Serviced			Serviced		Pod found on Texel undamaged		Deployed	**Collected**
AT 2	239	21	Deployed	Serviced			Serviced				Lost?	**Lost**
AT 3	233	17	Deployed	Serviced	Pod found on Dutch coast and sent to Denmark		Deployed				Serviced	**Collected**
AT 4	240	18	Deployed	Serviced			Serviced				Serviced	**Collected**
AT 5 (CTD 489)	234	18	Deployed	Serviced			Serviced				Serviced	**Collected**
AT 6	230	20	Deployed	Serviced			Serviced			Buoys were displaced, reset by the "Terschelling" T-Pod still attached	Serviced	**Collected**

Position name	T-POD	depth (m)	3-4/06/03	26/08 /03	11/10/03	20/11/03	02/12/03	10/12 /03	08/01/04	17/02/04	04/03/04	25-26/05/04
AT 7	231/276	19	231 Deployed	Serviced		Pod found on Hondsboschse zeewering and brought to police. Damaged, sent for repair	Not ready after repair				276 Deployed Aftercalibration	**Collected**
AT 8	232	18	Deployed	Serviced			Lost?	Pod found on Texel, completely stripped by the finder but still working. Sent for repair.			Deployed	**Collected**